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INTERNATIONAL WHEAT CONFERENCE

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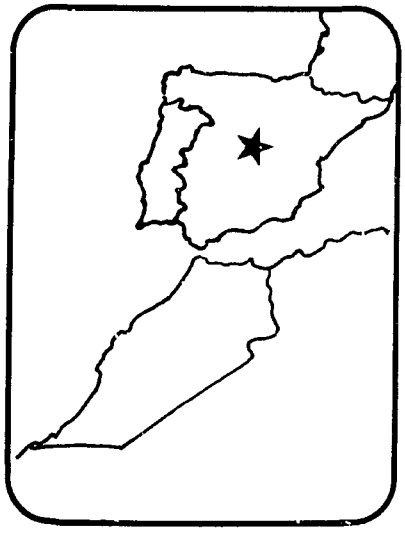
May 22 - June 3
1980



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POST-CONFERENCE TOUR

Monday, May 26

Depart Madrid for "El Encin" Farm.
Visit experimental fields.
Observe agriculture enroute to Badajoz, Spain.
Dinner and night at "Hotel Zurbaran", Badajoz.

Tuesday, May 27

Depart Badajoz for "La Orden" farm near Merida.
Visit experimental fields.
Drive to Elvas, Portugal.
Visit "Estacão Melhoramento de Plantas" at Elvas.
Observe agriculture enroute to Jerez de la Frontera, Spain.
Dinner and night at "Hotel Jerez", Jerez de la Frontera.

Wednesday, May 28

Visit INIA experimental fields near Jerez.
Visit "Museum of Watches" in Jerez.
Visit "Wine Museum" and a typical cave in Jerez.
Depart for Sevilla, Spain.
Dinner and night at "Hotel Don Paco", Sevilla.

Thursday, May 29

Depart for INIA experimental fields near Carmona, Spain.
Visit a typical farm.
Return to Sevilla, Spain.
Dinner and night at "Hotel Don Paco", Sevilla.

Friday, May 30

Depart for Algeciras, Spain.
Ferry to Tanger, Morocco.
Dinner and night at "Hotel Tanjhflandria", Tanger.

Saturday, May 31

Depart for Cereals Research Station at Fez, Morocco.
Visit wheat farm near Meknes, Morocco.
Sightsee in Fez.
Dinner and night at "Hotel Fez".

Sunday, June 1

Sightsee enroute to Rabat, Morocco.
Dinner and night at "Rabat Hilton Hotel", Rabat.

Monday, June 2

Visit Merchouch Cereals Research and Seed Station near Romani, Morocco.
Visit Hassan II Agronomic and Veterinary Institute and
National Institute for Agronomic Research in Rabat.
Depart for Tanger.
Dinner and night at "Hotel Tanjhflandria", Tanger.

Tuesday, June 3

Fly from Tanger to Madrid, Spain.
End of tour.

FOREWORD

This International Wheat Conference was the fourth in a series initiated by the USDA-SEA-AR and the University of Nebraska with major funding from the U. S. Agency for International Development. Prior conferences were held in Ankara, Turkey in 1972, Porto Alegre, Brazil in 1974 and in Zagreb, Yugoslavia in 1975. The Ankara and Zagreb conferences dealt with winter wheat only. The Latin American conference in Porto Alegre, Brazil and this conference addressed problems of all kinds of wheat.

This was the largest of the conferences to date. Participants numbered 227 from 40 countries. The program focused on problems of production and wheat improvement in rainfed semi-arid regions of the world in which most of the wheat is produced. An 8-day post-conference tour of central and southern Spain, eastern Portugal and northern Morocco provided opportunity for participants to observe rainfed semi-arid wheat production and to visit field research stations in the three countries at which wheat breeding and agronomic research is under way.

The conference and tour were sponsored by several organizations in Spain, Morocco, and the United States. These are identified on page i. Many people contributed to the organization of the conference and its program. I am particularly indebted to Prof. Sánchez-Monge and members of the Spanish Organizing Committee for the excellent conference arrangements. Their efforts contributed enormously to its success and helped to make it and the tour a memorable experience for participants -- particularly those who were visiting Spain, Portugal and Morocco for the first time. I am also indebted to my colleague at the University of Nebraska, Professor P. J. Mattern, who provided indispensable attention to financial and organizational matters prior to and during the conference. Finally, I thank all participants who presented papers and contributed to the discussions during the sessions.

Some manuscripts not presented at Madrid are included in this Proceedings. Insufficient time made impossible the presentations of all papers. A few speakers failed to provide written versions of their presentations as requested. In these cases only the abstracts have been included. An effort to record discussions from the floor was unsuccessful for failure of many participants to identify themselves and use available microphones during question and answer sessions. Manuscripts have been subjected to minimal editing to achieve a reasonable degree of conformity among them without alteration of intended meaning of the authors.

Participants were unanimous in their support of continuation of this series of international wheat conferences. There was general agreement that the interval between conferences should be 3 to 5 years. Possible site of the next conference was not discussed.

V. A. Johnson
USDA-SEA-AR
University of Nebraska
Lincoln, Nebraska

WELCOME ADDRESS

The Minister of Agriculture of Spain

Today's man, confronted with the menace of hunger and the increasing scarceness of the conventional energetic sources, demands more and more urgent solutions from scientists and technicians, hoping for an answer to his problems.

The need for attending this demand is producing an increasing solidarity between scientists all over the world. This Conference is a proof of it, being aware that the possible solutions must be reached through a close convergence of efforts and a greater and greater coordination of research and development activities.

We must not forget that the technological progress we are witnessing in our country involves also an increased inversion of resources that each new advance needs as it reaches levels more and more close to the possible economic optima. In the field of agronomic technology, we must be aware of the economic aspects of the problems to be solved as it would be senseless to propose technological advances that imply lost increases equal to or greater than the benefit increases reached with such advances.

Wheat growing, subject of this International Conference, is and has been of great importance for the world. It is not necessary to emphasize its importance here, but a well-known fact that is specially attractive is worth mentioning. Wheat, the first plant domesticated by man, also has been the first plant that indirectly has obtained for a man the Nobel Peace Prize.

Spectacular advances in yield have been reached in the last decades and fundamental to this achievement has been the introduction of the semi-dwarf wheats in different geographical areas through the work of the "Centro Internacional de Mejoramiento de Maiz y Trigo". In some areas these yields seem to be progressively decreasing due to a greater incidence of diseases (mostly rusts) and pests.

We are aware of the efforts of plant breeders, phytopathologists and agronomists toward the solution of these problems, and we are also aware of the difficulty of the task, due primarily to the great climatic, edaphic and even socio-economical diversity that exists between the multiple geographical areas

where wheat is grown for human consumption. Here again arises the need for solidarity of the work and for reinforcing the co-ordination of efforts between research workers all over the world with interchanges of material, technology and personal experiences.

Hybrid wheat, that some years ago was believed a possibility for spectacular yield advances, seems now to be more difficult to achieve as a practical result, due to the fact that increase in the seed cost is not yet absorbed by the increase in yield.

Spain has been and is today a cerealist country. With a total area of 50.5 million hectares of which 20.5 are under cultivation, more than 12.5 million hectares are devoted to spring and winter cereal production. Of these 12.5 million hectares 7.25 are sown yearly and the rest are in fallow.

barley and wheat represent more than 80% of the total of cereals. In the last decade wheat has seen a decrease in its acreage while that of barley has been increasing. In 1970 the acreage relationship between wheat and barley was 1.7. In 1974 it was 1.0 and in 1978 it was 0.8.

This progressive reduction of the wheat areas has been compensated by the increase in yield obtained with the use of new varieties. Spanish wheat consumption as human food is 3.6 million tons yearly. The production being greater than this figure, we have every year wheat surpluses that are used for feeds.

Durum wheat represents only a small percentage of the wheat area and in the last ten years the tendency has been toward a reduction of its area. In 1971 durum wheat was cultivated on 237 thousand hectares but only on 89 thousand hectares in 1978. Preliminary data from SEMPA for 1979 point toward an increase in durum wheat with an acreage of 105 thousand hectares.

The decrease in durum wheat area is surely due to the superior yields obtained with common wheat. New varieties of durum with higher yield are being obtained with the possibility of new gains for its acreage in the near future.

Wheat production in Spain is now faced with two main problems: low bread-making quality in the new high-yielding varieties and susceptibility to some diseases, especially stripe rust and septoria in southern Spain.

The Ministry of Agriculture, through its research institution, the "Instituto Nacional de Investigaciones Agrarias", is actively working on a solution to the problems mentioned through research projects on wheat and triticale of the National Research Program on Cereals.

Together with these activities, and being conscious of the need for international collaboration for solutions to the problems of all countries, the Spanish Government through the Ministry of Agriculture has achieved agreements of cooperation with several countries and institutions. It is worth mentioning here that tomorrow we are going to formalize an agreement with CIMMYT in order to increase cooperative activities that we already have been developing for some time.

PERFORMANCE OF CIMMYT WHEAT GERMPLASM IN OPTIMUM AND SUBOPTIMUM PRODUCTION ENVIRONMENTS

W. D. Worrall, N. H. Scott, A. R. Klatt, and S. Rajaram
CIMMYT

Introduction

The International Spring Wheat Rust Nursery (ISWRN), the first systematically organized international crop testing trial, was organized by the U.S. Department of Agriculture in an attempt to test an array of wheat genotypes for resistance to rust diseases over a large geographical area. The driving force in the organization of the nursery was the frequent and severe attacks of stem rust in the pandemic area of North America. The ISWRN was orginally distributed to cooperators in the Western Hemisphere, however, following the stem rust epidemic of the early 1950's, its distribution was expanded to include the Eastern Hemisphere. At this time the Food and Agriculture Organization of the United Nations became collaborators with the U.S.D.A. in the administration and support of the nursery.

Following the lead of the ISWRN, the Cooperative Inter-American Spring Wheat Yield Nursery was developed as a result of the 4th Meeting of the Latin American Plant Science Association in Santiago, Chile, in 1958.

Another international nursery, the Cooperative Near East-American Spring Wheat Yield Nursery, originated from the collective recommendations of Dr. Jose Villegas of the Argentine Ministry of Agriculture and Dr. Norman Borlaug of the Rockefeller Foundation during their assignments as consultants to FAO in 1960.

The International Spring Wheat Yield Nursery (ISWYN), begun in 1964, was an attempt to combine the above two regional nurseries. Its intention was to provide a mechanism for the dissemination of the most recently released spring wheat varieties throughout the world and to supply information on yield, disease resistance and wide adaptation to the bread wheat breeding program of the International Maize and Wheat Improvement Center (CIMMYT). This information was to be used to assist in directing the formation of new hybrids. As an adjunct, the ISWYN has served to answer some key questions concerning the overall effectiveness of the methodologies which have evolved from years of cooperative research with national programs.

The CIMMYT base breeding program involves two crop cycles per year in Mexico: 1) a summer cycle in Toluca, at an elevation of 2,640 m where genotypes are screened for resistance to the three rusts and other foliar pathogens, and 2) a winter nursery in Ciudad Obregon at an elevation of 40 m where material is screened

CIMMYT, Mexico and Oregon State University

for resistance to leaf and stem rusts and evaluated for yield potential. CIMMYT's long term objective is to develop, in cooperation with national and local wheat development programs throughout the world, germplasm that is: 1) high yielding, 2) widely adapted, 3) light insensitive, and 4) disease resistant.

The two-location testing system of early generation material plus a network of international nursery cooperators provide the mechanism to pursue that objective.

CIMMYT's seed dissemination system is extensive. In 1979-80, 2276 international nurseries of bread wheat, durum wheat, barley and triticale were sent to 307 cooperators in 116 countries, also, a large number of special seed requests were filled. The international nurseries consist primarily of advanced generation material. For more than a decade, however, F_2 generation materials have been sent to cooperators who wish to carry out their own selection program.

The net result of this approach has been an unprecedented rapid acceptance of what have become known as high yielding varieties (HYV) throughout the world, the majority of which have originated from CIMMYT germplasm. According to Dalrymple (1978) the approximate area under HYV of wheat in the growth cycle 1976-77 for the developing world (excluding Taiwan, Israel, South Africa and Eastern block nations) was 29,297,300 hectares which was about 44.2% of the total area planted to wheat by the 24 reporting countries. The rapid rate of adoption is evidenced by the statistics for the 1974-75 season in which 15 countries were surveyed. Here the HYV wheat area was about 21.9 million hectares.

To maintain a dynamic program of germplasm development, it is essential to constantly scrutinize current breeding methodologies. CIMMYT utilizes two types of scrutiny: by soliciting appraisals and recommendations from national program cooperators, who are an integral component of the system, and by analyzing data supplied by these cooperators.

The question is often asked, "Does CIMMTY develop germplasm that is, in fact, high yielding and widely adapted, fitting both (a) high yield production environments and (b) areas of traditionally low wheat yields?" Analyses reported in this paper deal with that question. In addition to high yield environments such as northern Mexico where much of the germplasm development occurs, data come from sites with such production constraints as heavy rust epidemics of Kenya and the Andean region of Latin America, the Helminthosporium infections in many tropical environments, and insufficient moisture, a severe production contraint on at least 7.5 million hectares disregarding Latin America and China (Byerlee and Winkelmann, 1980).

Evidence from these analyses weigh heavily toward an affirmative answer to the question.

Materials and Methods

The ISWYN is a standardized yield nursery consisting of three replications of 49 commercial cultivars and advanced lines plus one local check. It is grown in plots of six 2.5 m rows of which the central four rows are harvested for yield evaluation.

Fourteen years of yield data from the ISWYN were accumulated for this analysis, screened and categorized as follows:

1) Data were discarded from (a) any location for which the individual yearly analysis of variance resulted in an inordinately high coefficient of variation and (b) any location with less than six years of reliable data. In total, 419 location-years of data were analyzed. Classification of locations into yield-level categories was not meaningful due to the large deviations in individual nursery means between years.

2) The first two ISWYNs consisted of 25 commercially grown cultivars; the other 12 were made up of 49 advanced lines and commerical cultivars plus one local check, 50 entries each. Because the local check was frequently not identified, it was excluded from this analysis.

3) All varieties were classified into three groups as follows:

   a) Those cultivars bred by CIMMYT but named and released by national programs without further selection. (Some CIMMYT advanced lines were also included in this group.)

   b) Cultivars whose early development was by CIMMYT, but at least one further selection was made in a national program prior to its naming and release.

   c) Cultivars developed completely in national programs. These classifications were made on the basis of available information. It is recognized, however, that some of the cultivars classified in group C actually contain substantial proportions of CIMMYT germplasm. (The variety 'Condor', developed in Australia and tested in ISWYN 11 through 14, is a product of the cross WW15-Jaral "S"; both parents came directly from the CIMMYT program.)

4) Locations were categorized into regions as shown in Table 1. While somewhat arbitrary, these groupings are meant to combine locations of like geography and environment. For example, region 9, the Southern Cone region of South America, does not include areas of Brazil where aluminum-toxic soils are a problem.

Keypunching and computer analyses were done at Oregon State University. The regression analyses used were similar to those

outlined by Finlay and Wilkinson (1963) and Eberhart and Russell (1966) in which the regression of variety mean yield on nursery mean yield is used as a reliable estimate of cultivar stability of performance over a range of environments. These procedures were modified to compare groups of cultivars over a range of environments.

Table 1. Regions of ISWYN trials.

Region	Area
1	Middle East, Egypt, Sudan, and Libya
2	Mediterranean region (Algeria, Tunisia, Morocco, Southern Spain and Portugal)
3	Indian Subcontinent
4	Far East and Oceania
5	Europe (other than Spain and Portugal)
6	Northern U.S. and Canada
7	Northern Mexico and southern U.S.
8	Highlands (Andean region and East African Highlands)
9	Southern Cone other than aluminum toxic soils

Results and Discussion

According to the varietal categories utilized by Finlay and Wilkinson, the ideal response for widely adapted, high yielding material is a regression coefficient as close to 1.00 as possible with cultivar mean yield well above nursery mean yield across an array of environments. Thus, CIMMYT strives to develop high yielding germplasm with "average stability" over all environments. In other words, the desired cultivar is one which is input-responsive as well as input-efficient. In traditionally low yielding environments these cultivars yield well above the nursery mean (input efficient) and as the level of inputs increase and the quality of the environment improves, both edaphic and climatic, the yield of the desired cultivar improves accordingly (input responsive).

Prior to release to national programs through the ISWYN and the International Bread Wheat Screening Nursery, CIMMYT materials are evaluated for yield potential in the irrigated, high yielding

environment of Ciudad Obregon only. Nevertheless, information returned from cooperators, as well as data received from CIMMYT's regional programs, serves to direct the formation of new hybrids in such a way that widely adapted parents predominate. This integration of the base breeding program, national programs and regional programs, we believe is the key ingredient in the successful development of high yielding, widely adapted germplasm.

Figure 1 displays the results of linear regression analysis of cultivar mean yield on nursery mean yield over the 14 years covered in this analysis for the three groups of cultivars described earlier. (Group A includes those lines bred by CIMMYT which were chosen, named, and released by national program officials with no further selection. Group B includes materials originally developed by CIMMYT with at least one further selection in a national program before naming and release.) Line C is included in this, and other figures, only from comparison. That line represents the combined performance of Group C cultivars, those released by national and local breeding programs where objectives are cultivars with relatively more specific adaptation; they would not be expected to have the same range of adaptation as germplasm specifically developed for wide adaptation. However, comparison should be valid between yielding ability of these locally developed and CIMMYT-developed lines, especially in higher yielding locations.

As shown in Figure 1, Group A cultivars across environments and over years, have proven to be slightly higher yielding and of essentially equal stability of performance as Group B cultivars. Coefficients of determination (r^2) for these two groups were respectively 0.81 and 0.82, indicating that the yields of both groups are of essentially equal predictability.

The data illustrate that Group C material, in general did not have the yield potential of the cultivars in either Group A or Group B in any of the test environments analyzed nor did it show the same characteristic of stability across environments; its regression coefficient having a value well below 1.00. In addition, Group C cultivars exhibited a lower level of predictability with a coefficient of determination of 0.68.

Figure 2 exhibits the lower and upper bound confidence interval estimates for the regression lines in Figure 1. This further supports the contention that the Group A cultivars do, in fact, possess characteristics for high yield potential. Lower bound confidence interval estimates for Groups B and C are substantially lower than that of Group A. The most striking difference, however, is in the upper bound estimates, where the higher yielding ability of Group A cultivars is obvious. This figure also demonstrates the increased stability (lower variance) of Group A material particularly at high yield levels.

To determine if the 14 year analysis conceals any shorter-term

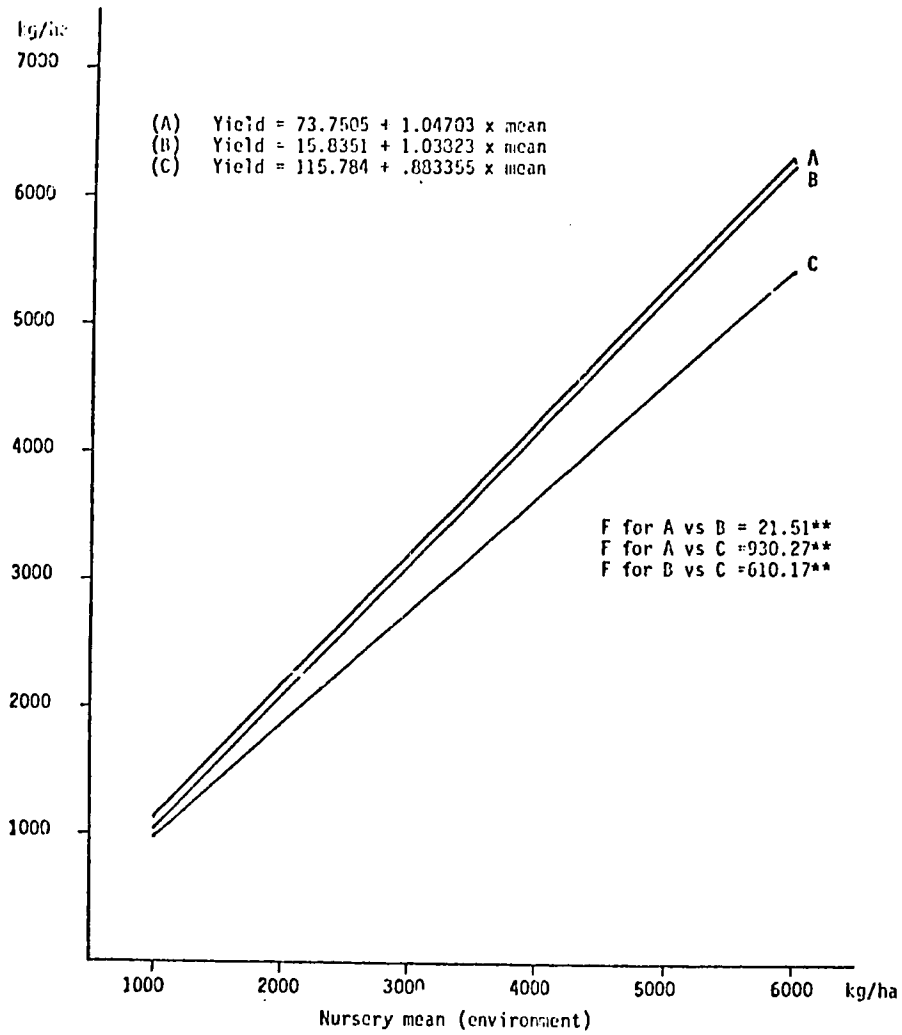

Fig. 1. Yields of three groups of spring wheat cultivars regressed over nursery mean yield. Data from First through 14th ISWYN.

A = CIMMYT advanced lines or CIMMYT lines released in national programs without further selection
B = CIMMYT lines released after further selection in national programs
C = Cultivars developed wholly within national programs

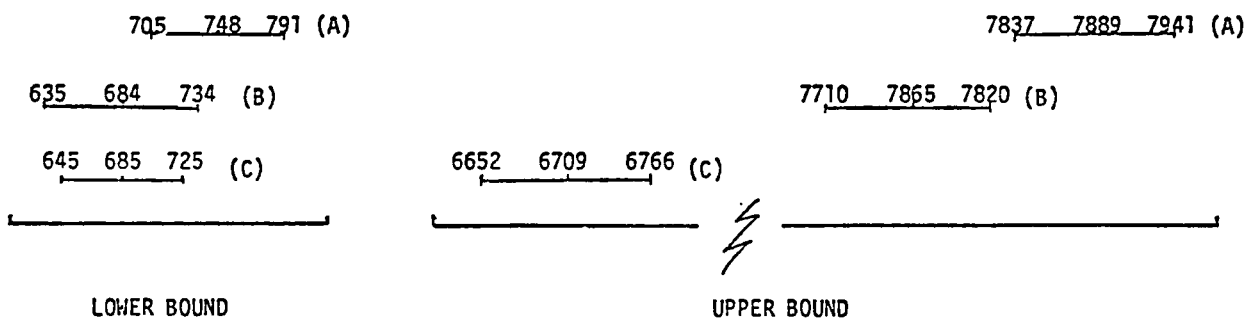

Fig. 2. Lower and upper bound confidence interval estimates (P = .95) for groups of cultivars regressed over environments. Data from First through 14th ISWYN.

For group definitions, see notes with Fig. 1.

trends in Group A cultivars, the data were separated into three interval groups, two of 5 years and one of 4 years. Linear regression analysis produced data depicted in Figure 3: D represents the first five ISWYN years, E the second 5-year period and F the last 4 years. These data indicate a substantial increase in stability across all environments, with respective regression coefficients of 1.11, 1.10, and 1.04 for lines D, E, F. Coefficients of determination for lines D and F were 0.73 and 0.82, respectively, indicating the Group A germplasm has in the last 14 years gained significant stability and predictability of performance over all types of environmental conditions.

Group B has been subject to similar trends to those disclosed for Group A. The regression lines shown in Figure 4 and respective r^2 values (0.76, 0.82, and 0.85) indicate the similarities.

Regression analysis of Group C materials gave the data for Figure 5. Values of r^2 (0.64, 0.67, and 0.72, respectively) indicate an increase in yield predictability over the three periods. However, regression coefficients of 0.94, 0.86, and 0.87, respectively, show some reduction in ability of these cultivars to respond to improvements in environments. (Lines E and F are statistically equal in this figure.)

A superficial examination of Figures 3, 4, and 5 may lead to the conclusion that all material in the ISWYN has lost yield potential. That is not the case. In fact, the overall nursery mean has increased from 2984 kg/ha for the first five years of the ISWYN to 3640 kg/ha in the second five year period and 4106 kg/ha for the last four years. Mean yields for the three cultivar groups have also increased steadily as seen in Table 2. Differences between nursery mean yield and mean yield of Groups A and B have decreased in such successive time increment. The same differences for Group C material have been erratic. Consequently, the responses seen are those of higher relative performance of all cultivar groupings in combination with greatly improved nursery management by cooperators rather than a steady loss of yield potential. This conclusion is supported by the fact that small but significant increases in yield have been recorded consistently in Ciudad Obregon to the extent that several lines exhibit yield potential in excess of 8.0 metric tons per hectare.

Figures 6 through 14 illustrate the results of regression analysis on a regional basis of Group A and Group B material combined vs. Group C material (Groups A and B have been combined for ease of analysis since they show similar responses across environments). In general, the same trends are apparent over years for each region analyzed. Slight deviations appear in the slopes of the regression lines and in r^2 values, however, the same relationship is maintained between the two groups of cultivars. Of notable interest, however, are the relationships shown for the region of the northern United States and Canada, Figure 13 and the European region, Figure 14. Many of the

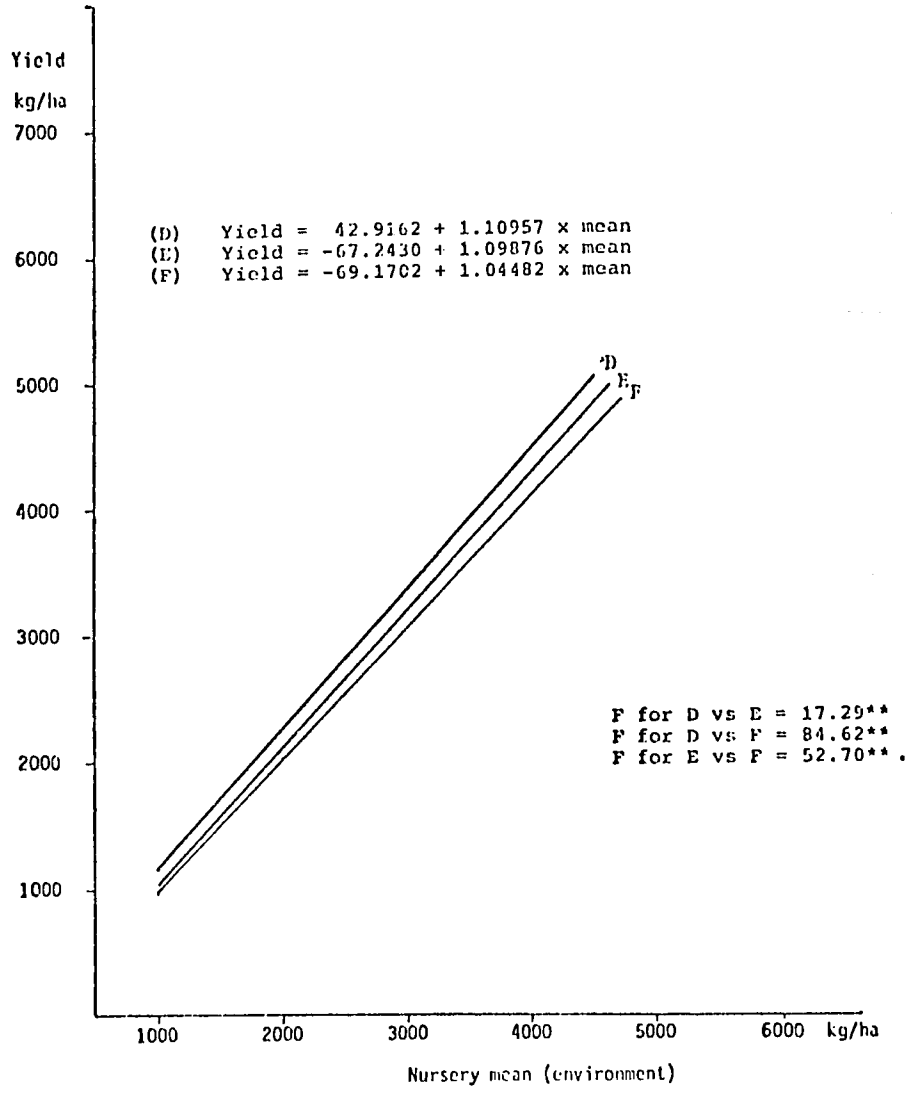

Fig. 3. Yields of CIMMYT advanced lines and CIMMYT lines released in national programs without further selection regressed over corresponding nursery means for three time periods. Data from First through 14th ISWYN.

D = first 5 years; E = second 5 years; F = most recent 4 years

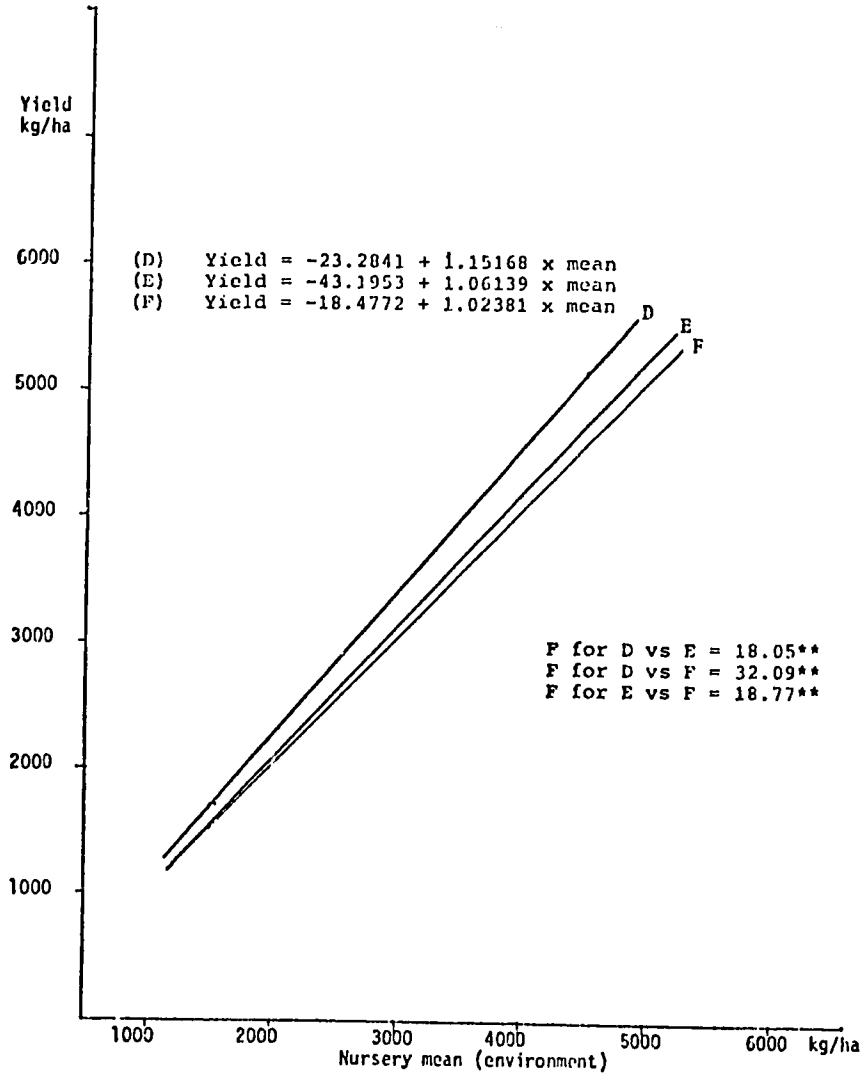

Fig. 4. Yields of CIMMYT lines released after further selection in national programs regressed over corresponding nursery means for three time periods. Data from First through 14th ISWYN.

D = first 5 years; E = second 5 years; F = most recent 4 years

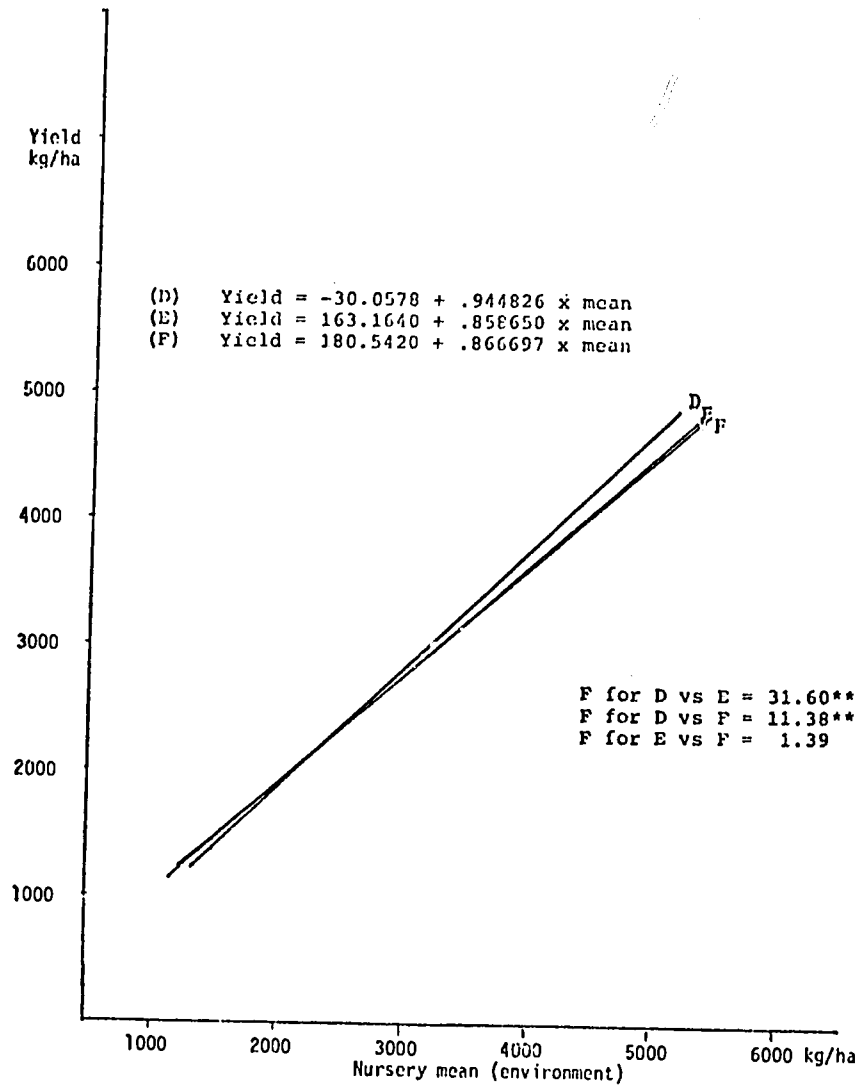

Fig. 5. Yields of cultivars developed wholly within national programs regressed over corresponding nursery means for three time periods. Data from First through 14th ISWYN.

D = first 5 years; E = second 5 years; F = most recent 4 years

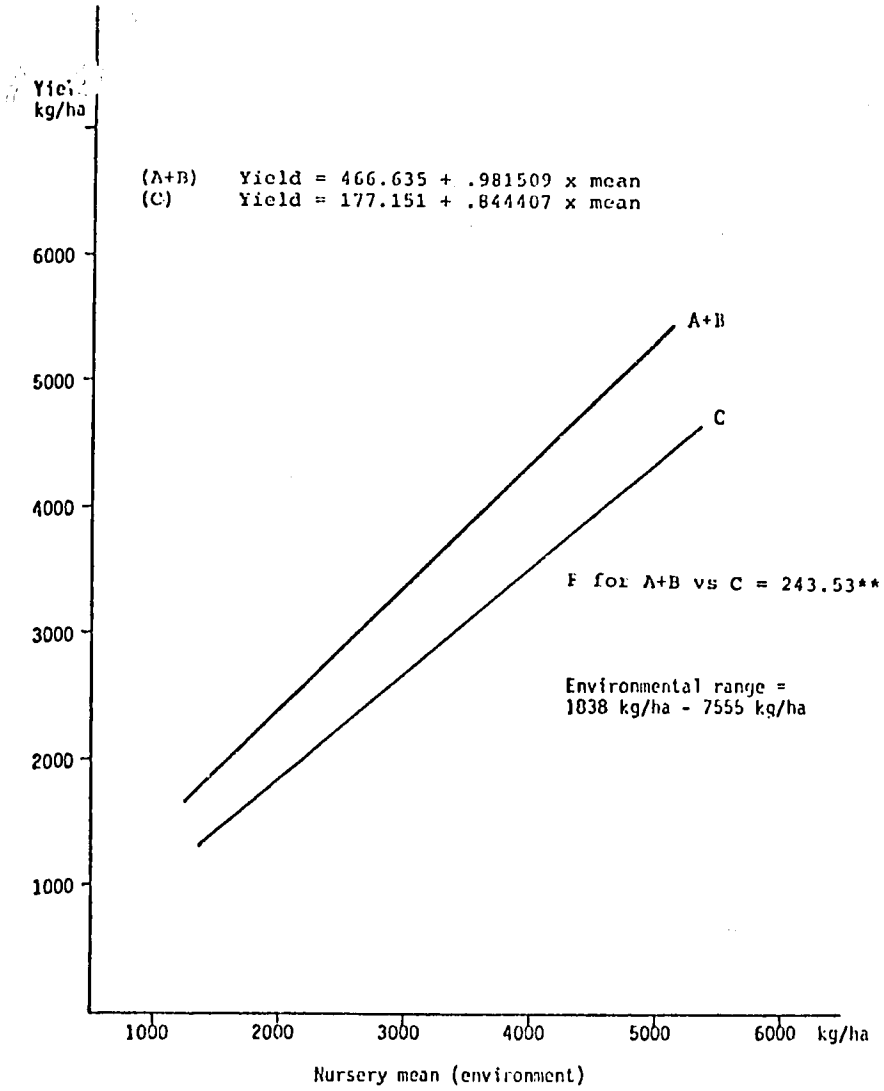

Fig. 6. Yields of two groups of cultivars regressed over environments (mean of nurseries) in region of northern Mexico and southern United States. Data from First through 14th ISWYN.

A + B = Combined Groups A and B as defined in footnote, Fig. 1
C - Group C as define in footnote, Fig. 1

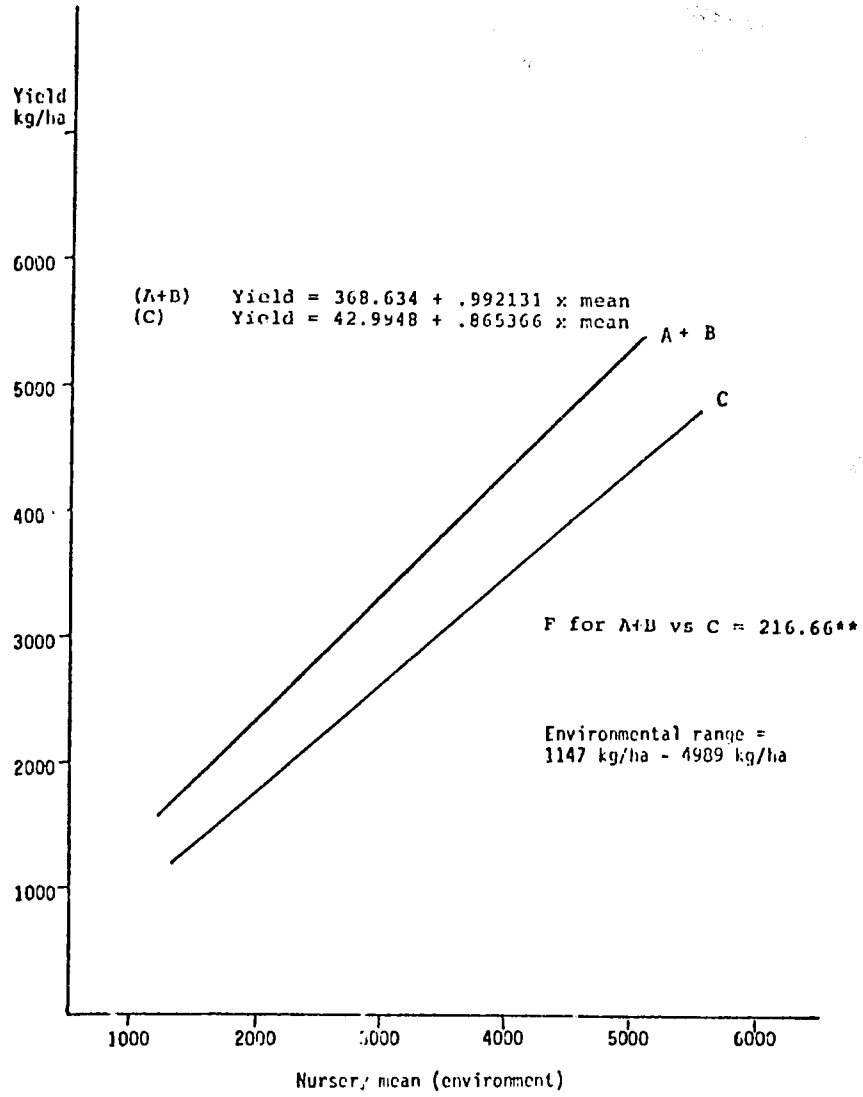

Fig. 7. Yields of two groups of cultivars regressed over environments (means of nurseries) in region of Indian Subcontinent. Data from First through 14th ISWYN.

See footnote, Fig. 6

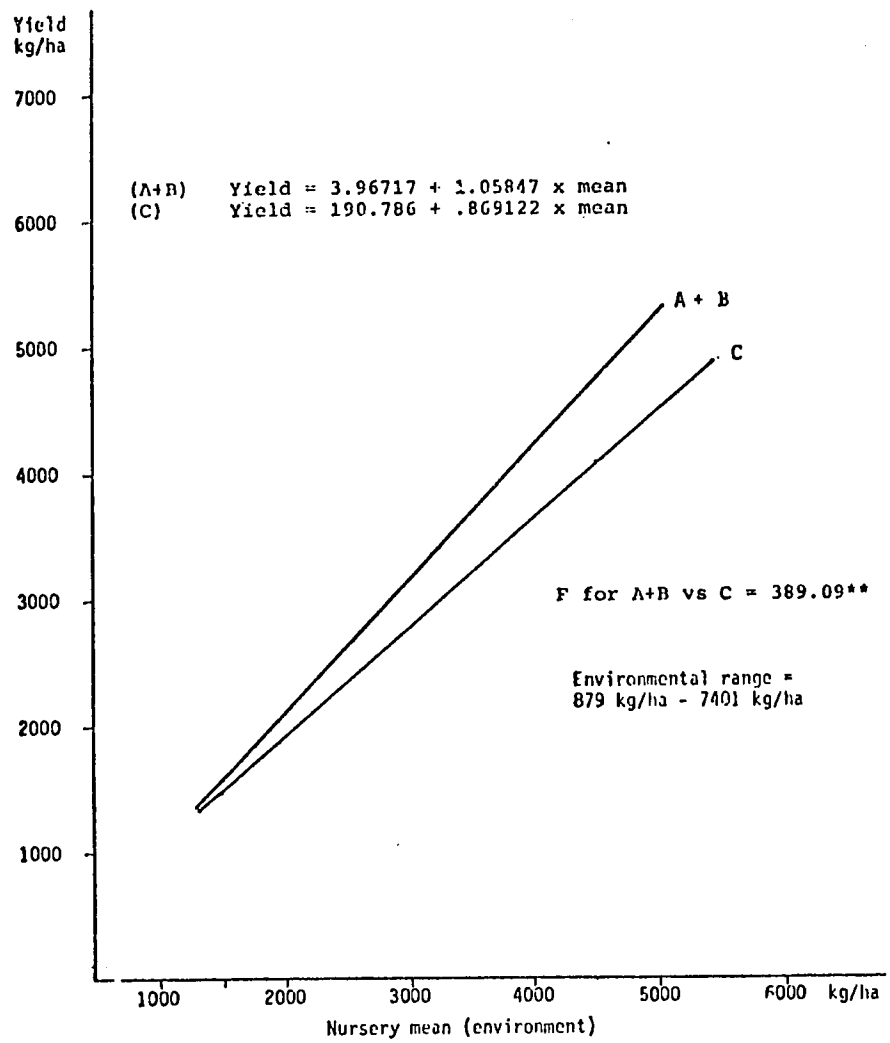

Fig. 8. Yields of two groups of cultivars regressed over environments (means of nurseries) in region of Middle East, Egypt, Sudan and Libya. Data from First through 14th ISWYN.

See footnote, Fig. 6

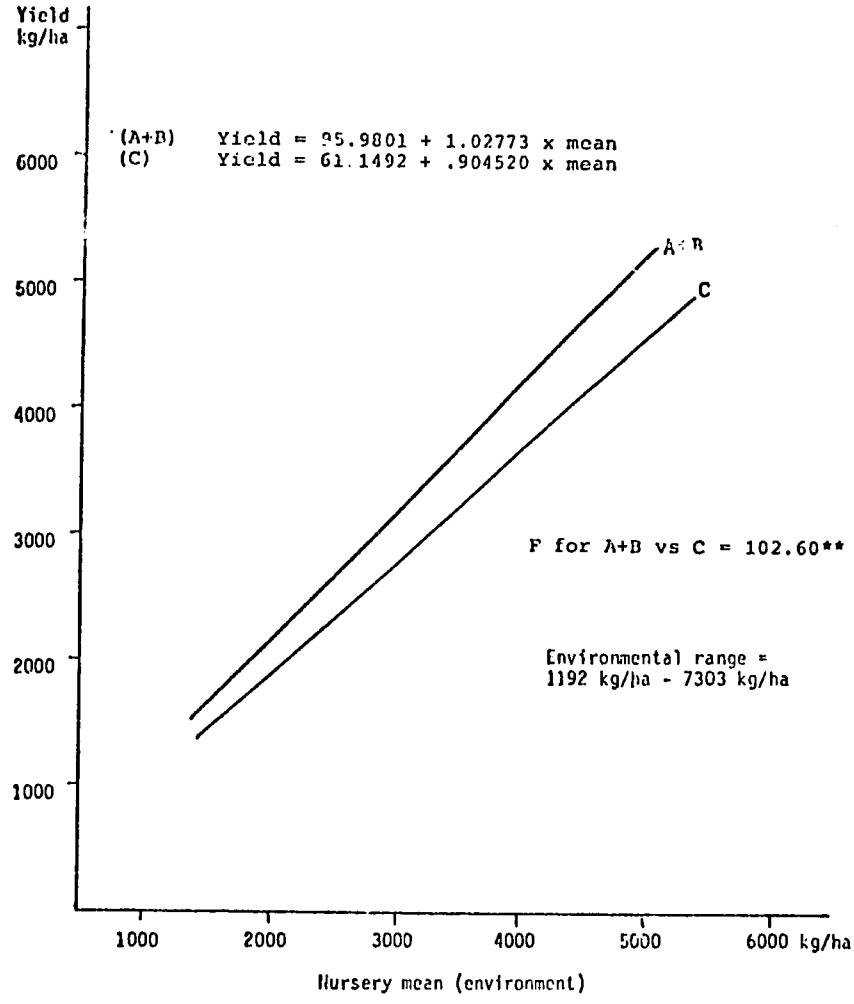

Fig. 9. Yields of two groups of cultivars regressed over environments (means of nurseries) in Mediterranean region. Data from First through 14th ISWYN.

See footnote, fig. 6

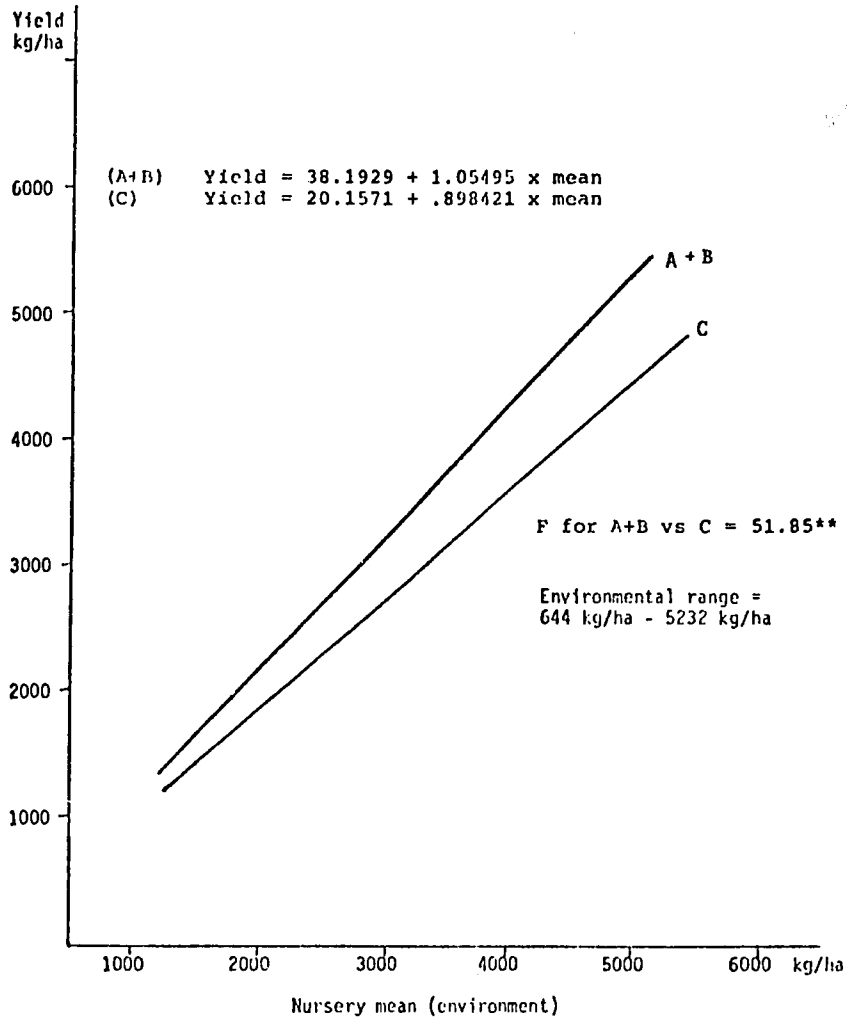

Fig. 10. Yields of two groups of cultivars regressed over environments (means of nurseries) in highlands of North Africa. Data from First through 14th ISWYN.

See footnote, fig. 6

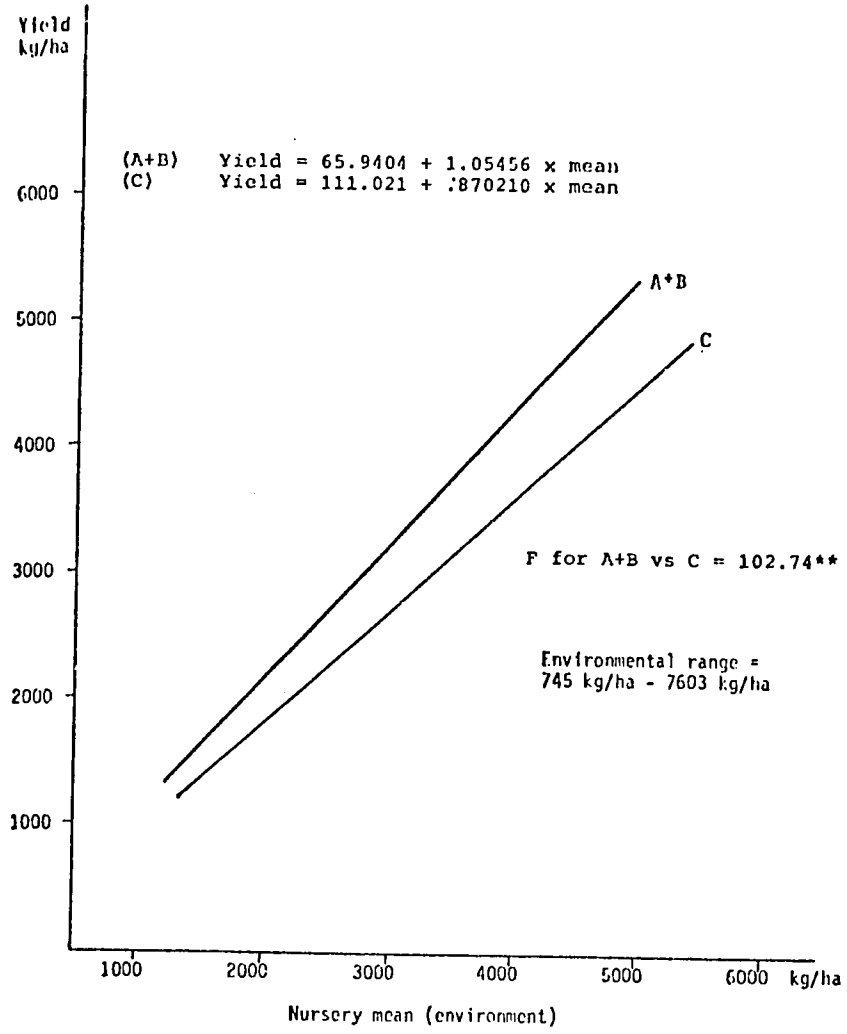

Fig. 11. Yields of two groups of cultivars regressed over environments (means of nurseries) in Southern Cone region of South America. Data from First through 14th ISWYN.

See footnote, fig. 6

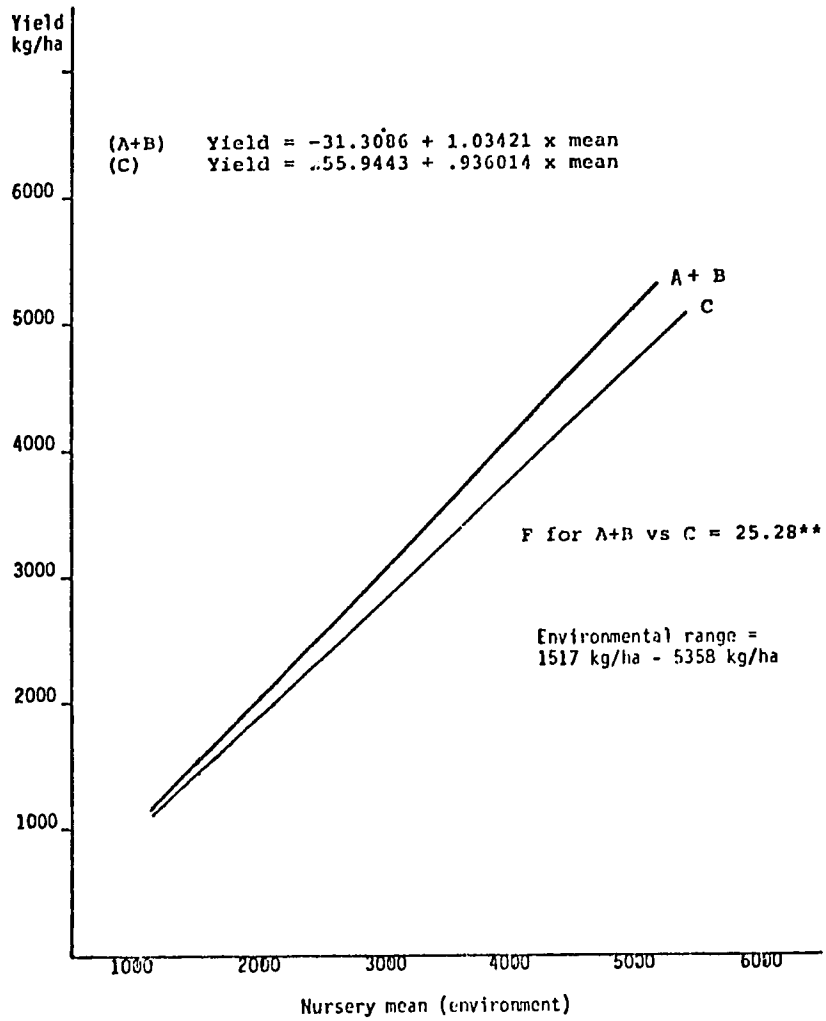

Fig. 12. Yields of two groups of cultivars regressed over environments (means of nurseries) in region of Far East and Oceania. Data from First through 14th ISWYN.

See footnote, fig. 6

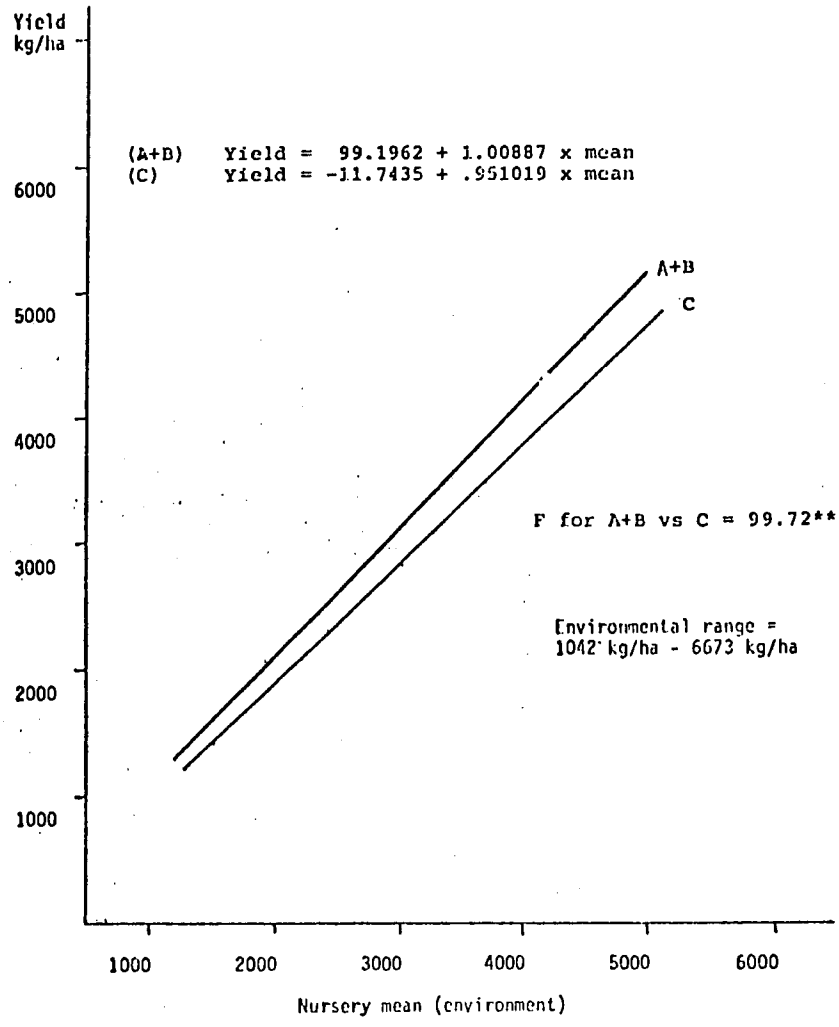

Fig. 13. Yields of two groups of cultivars regressed over environments (means of nurseries) in the region of northern United States and Canada. Data from First through 14th ISWYN.

See footnote, fig. 6

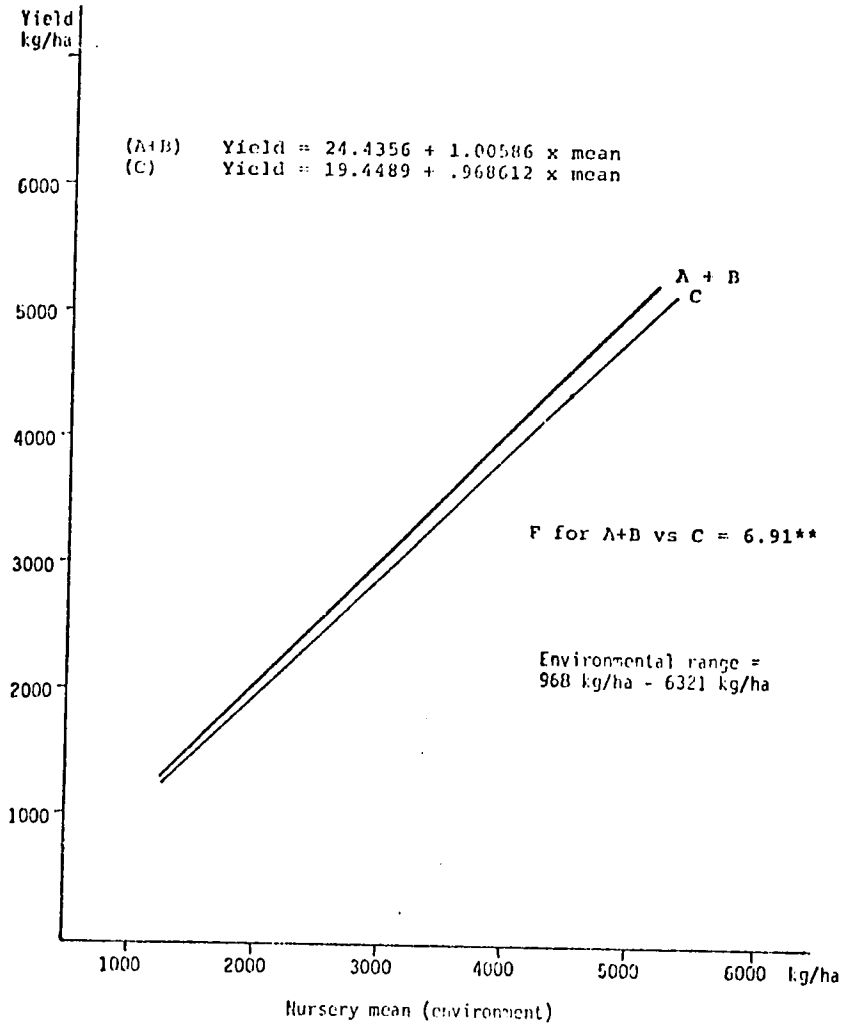

Fig. 14. Yields of two groups of cultivars regressed over environments (means of nurseries) in region of Europe, excluding Spain and Portugal. Data from First through 14th ISWYN.

See footnote, fig. 6

varieties included in the ISWYN over the years have originated from highly advanced programs in these regions. Some examples are 'Selkirk', 'Era', 'Thatcher', 'Manitou', 'Justin', and 'Glenlea' from the northern U.S. and Canada and '715/70' and '521/69' from Yugoslavia.

Table 2. Mean yield (kg/ha) of three groups of spring wheat cultivars for 3 time increments of the International Spring Wheat Yield Nursery.

Cultivar group	First 5 years	Second 5 years	Last 4 years
A	3348	3944	4228
B	3298	3974	4173
C	2797	3184	3740

A high degree of daylength insensitivity is necessary for adaptation over a wide latitudinal range. Therefore, this characteristic has been incorporated into CIMMYT germplasm. In contrast, many cultivars originating in the northern United States, Canada, and Europe possess a relatively high degree of sensitivity to daylength; an important characteristic in these regions in order to confer specific adaptation. This explains, in part, the relatively similar responses of the combined Groups A and B cultivars as compared to Group C in these regions. Nevertheless, Groups A and B cultivars retain their advantage. An example of this is seen from data reported from Landskrona, Sweden, and St. Paul, Minnesota. In five of the eight years that Landskrona returned yield data, Group A cultivars were the highest yielding. Group A cultivars were also the highest yielding in four of the seven nurseries grown in St. Paul.

The above data indicate that CIMMYT's breeding program in partnership with national programs has been effective in the development of high yielding spring wheat germplasm and that significant progress has been made and is continuing in breeding for stability of performance over a wide range of environments.

In other words, the germplasm is displaying a combination of input efficiency and input responsiveness, traits needed for better adaptation to the highly variable growing conditions around the world.

Table 3 shows the varietal composition of the 14 ISWYN's used in this report and is an indication of the acceptance and use of CIMMYT germplasm. Candidate varieties for possible inclusion in the ISWYN are actively solicited from breeding programs throughout

the world. Although each candidate is evaluated for general agronomic value in Ciudad Obregon, no potential ISWYN entry is discarded due to its yield performance in Mexico. The critical selection criterion is disease resistance. CIMMYT strives to include as many non-CIMMYT entries in the ISWYN as possible. Nevertheless, Table 3 shows the predominance of Groups A and B cultivars increasing over the 14 year period to a point where Group C entries appear to have stabilized at about 20% of the total. This apparently is a reflection of the exploitation by national programs of the CIMMYT germplasm, particularly in developing countries.

Table 3. Origin of cultivars, by three sources, included in First through 14th International Spring Wheat Yield Nursery.

ISWYN No.	Group A	Group B	Group C
1	6	0	19
2	9	0	16
3	14	0	36
4	15	3	32
5	15	4	31
6	11	5	33
7	15	14	20
8	12	16	21
9	12	22	15
10	13	24	12
11	25	14	10
12	24	14	11
13	22	15	12
14	24	15	10

Group A = CIMMYT advanced lines or CIMMYT lines released in national programs without further selection.

Group B = CIMMYT lines released after further selection in national programs.

Group C = cultivars developed wholly within national programs.

The question of whether or not CIMMYT might better serve the needs of developing countries and, in particular, areas with traditionally low production levels, by modifying its breeding methodology to include selection for low yielding environments is not directly answered by this analysis. However, the data already presented show that high yielding, stable germplasm is being successfully produced by CIMMYT and its national program cooperators and that the stability over a wide range of environments has improved continually over the past 14 years. The rate and extent of

infusion of CIMMYT germplasm into national programs, in itself, is empirical evidence of the utility of such material across the array of production environments. Further evidence is presented in Table 4 where, at individual locations with nursery mean yields less than 2000 kg/ha the top-ranking variety was categorized according to varietal type. Although the relationship between Groups A and B cultivars and Group C cultivars is not constant, the trend is relatively clear. Group A and B material has performed well in low yielding environments over all 14 years of data but have clearly dominated in the last 6 years. This is a demonstration of their input efficiency. Tables 5 and 6 serve to further emphasize the superior yielding potential and input responsiveness of these cultivars. Here the top-ranking cultivar in medium-level input environments (2000 to 4000 kg/ha) and upper-level input environments (>4000 kg/ha) respectively, were classified according to origin. Again, the frequency with which Groups A and B cultivars achieve top ranking is quite clear. Consequently, it is apparent that the breeding methodologies currently employed by CIMMYT in cooperation with national breeding programs and backstopped by the international testing network and regional programs have been effective in the development of high yielding, widely adapted cultivars which perform well at all levels of input technology.

Table 4. Origin of top-yielding cultivars in low production environment (nursery mean less than 2000 kg/ha) for First through 14th ISWYN.

ISWYN	Group A	Group B	Group A + Group B	Group C
1	3	0	3	6
2	9	0	9	11
3	8	0	8	11
4	7	4	11	6
5	10	3	13	6
6	2	5	7	10
7	0	3	3	6
8	5	4	9	5
9	4	4	8	4
10	4	4	8	1
11	5	1	6	1
12	7	3	10	1
13	6	1	7	6
14	8	2	10	2

Group A = CIMMYT advanced lines or CIMMYT lines released in national programs without further selection.
Group B = CIMMYT lines released after further selection in national programs.
Group C = cultivars developed wholly within national programs.

Table 5. Origin of top-yielding cultivars in medium production environment (nursery means between 2000 and 4000 kg/ha) for First through 14th ISWYN.

ISWYN No.	Group A	Group B	Group A + Group B	Group C
1	17	0	17	5
2	19	0	19	4
3	25	0	25	6
4	24	2	26	10
5	27	5	32	5
6	18	2	20	11
7	16	7	23	9
8	12	11	23	13
9	13	17	30	1
10	8	27	35	4
11	18	15	33	2
12	15	15	30	2
13	24	6	30	9
14	22	9	31	5

Group A = CIMMYT advanced lines or CIMMYT lines released in national programs without further selection.
Group B = CIMMYT lines released after further selection in national programs.
Group C = cultivars developed wholly within national programs.

Table 6. Origin of top-yielding cultivars in high production environment (nursery means over 4000 kg/ha) for First through 14th ISWYN.

ISWYN No.	Group A	Group B	Group A + Group B	Group C
1	3	0	3	0
2	5	0	5	1
3	11	0	11	1
4	7	2	9	1
5	5	0	5	2
6	4	2	6	6
7	14	6	20	5
8	13	14	27	4
9	15	10	25	1
10	10	11	21	2
11	12	8	20	1
12	24	5	30	3
13	10	9	19	2
14	18	3	21	0

Group A = CIMMYT advanced lines or CIMMYT lines released in national programs without further selection.
Group B = CIMMYT lines released after further selection in national programs.
Group C = cultivars developed wholly within national programs.

If there were to be a change in breeding methodology, there is some question as to what new selection criteria are of sufficiently severe magnitude to necessitate inclusion in the breeding program. Certainly drought tolerance is a severe yield contraint but we have not, as yet, been able to characterize the many different types of drought into a workable selection scheme. If it is possible to do so and if it is possible to categorize other sufficiently severe yield constraints, it is doubtful that any breeding program with a finite amount of resources, both financial and human, could efficiently and effectively handle the number of selections which would be required. Nevertheless, in cases where substantial areas of wheat production or potential wheat production are involved and where the solutions to yield constraints are known to be heritable, CIMMYT and its national program counterparts have, in the last 5 years, been involved in shuttle breeding projects in an attempt to assist in the development of germplasm in which these specific characteristics have been incorporated. In alternating cycles between Mexico and the specific area or region, CIMMYT crosses, selects and tests material which, during the following cycle, will be sent for evaluation and final selection to the national programs. Examples of such projects are the cooperative programs with Brazil for the development of cultivars which are resistant to aluminum toxicity in acid soils; the development of facultative wheats for the highlands of North Africa; the incorporation of Septoria resistance for Mediterranean areas; and the development of early maturing lines with a long vegetative phase for use in Central India. The intimate involvement of the national programs in this regard is of utmost importance because they are primarily responsible for the identification of material ideally suited to their conditions of stress.

The evidence presented here shows that CIMMYT and its national program cooperators have been able to effectively meet the demand for germplasm which fits into nearly every wheat-growing environment. Rather than alter the established system of producing germplasm, it would appear to be more efficient to support and encourage national programs to select lines which satisfy their specific adaptation requirements from the large volume of germplasm made available annually by the CIMMYT program.

References Cited

Byerlee, D. and D. L. Winkelmann. 1980. Accelerated wheat production in semi-arid developing regions: economic and policy issues. Paper presented at the International Wheat Conf., Madrid, Spain.

Dalrymple, D. C. 1978. Development and spread of high yielding varieties of wheat and rice in the less developed nations. USDA. Foreign Agricultural Economic Report No. 95.

Eberhart, S. A. and W. A. Russell. 1966. Stability parameters for comparing varieties. Crop Sci. 6:36-40.

Finlay, K. W. and G. N. Wilkinson. 1963. The analysis of adaptation in a plant-breeding programme. Aust. J. Agric. Res. 14:742-754.

BREEDING SYSTEMS FOR RAINFED WHEAT IMPROVEMENT IN SEMI-ARID REGIONS

J. W. Schmidt
United States

Abstract

The literature dealing with the breeding of crops for semi-arid conditions generally suggests that at least three processes are involved. These are: 1) drought tolerance or avoidance; 2) more efficient water use; and 3) adaptation or desirable genotype by environment interaction.

It is most efficient to select a crop maturity that maximizes growth and accompanying yield component development. In semi-arid regions this has tended to be an early maturity with rapid early season growth and development of the tillering component. However, once the breeding populations have been shifted to the appropriate maturities, no further progress via this approach will be obtained.

Since studies of characteristics related to drought tolerance are difficult (e.g. root studies), careful choices of parental materials after extensive study is indicated. Techniques for selecting for improved water-use efficiency at the practical plant breeding level generally are not available at this time.

Exploiting breeding procedures that serve to identify populations and breeding lines early in the breeding program with desirable genotype by environment interactions appears to be of paramount importance. Multilocational testing of early generation bulks, F_2-F_3-derived lines, F_2 selection composites, or multilocational selection should be explored. At the moment high overall yield is still the best criterion for selection. The earlier in the breeding program that adaptive (high average) yield can be identified the better. Phenotypic uniformity, while aesthetically desirable, does not assure productive performance. Variability, within limits, may provide population buffering in climatically highly variable semi-arid regions.

Most of the world's wheat is produced under rainfed conditions and much of that represents areas of limited rainfall. Thus, one would expect to find a considerable body of literature dealing with successes in breeding of wheat under dryland or semi-arid conditions. Not so. A recent literature search using a computer retrieval system at the University of Nebraska turned up very few examples. Why is this the case when many wheat breeders at many locations are breeding wheats for semi-arid conditions? Obviously, breeding wheats

University of Nebraska-Lincoln

for such conditions is very complex and few definitive studies or examples of progress stand out. Further, Turner (1977) points out that drought occurs in many different forms and that the "type of drought encountered must be established" before a breeding program can begin.

Papers dealing with the breeding of crops for semi-arid conditions generally suggest that at least three processes are involved. These are: 1) drought tolerance or avoidance; 2) more efficient moisture use; and 3) adaptation or desirable genotype by environment interaction.

Since increasing yield is a prime objective in breeding programs, the question arises as to which of the above can be related to yield improvement. What about drought tolerance or drought avoidance? Breeding for earliness or appropriate maturity is a means of drought avoidance and can be associated with yield improvement. Reitz (1974) reported that, in the Great Plains of central United States, earliness (from 1 to 20 days earlier) in relation to the moderately late maturing variety Kharkof was worth 0.6 q/ha for each day earlier at Woodward, Oklahoma, 0.54 q/ha at Manhattan, Kansas, and from 0.6 to 1.2 q/ha at Lincoln, Nebraska. However, once the optimum maturity had been achieved no more progress was possible. Similarly, in most wheat producing regions, optimum maturities have already been established.

Mac Key (1970) suggests that advantages of earliness are related to the usual presence of the best conditions for growth early in the growing period and thus will be correlated with those components of yield that develop early ontogenetically. Characteristically that principal component would be a high number of tillers per unit area with an expected lower number of kernels per spike leading to low to moderate yield levels. Mac Key further points out that the very high yields in western and northern Europe are correlated with yield components that develop later ontogenetically leading to a high number of kernels per spike and a high kernel weight. Thus, breeding for enchanced expression of those ontogenetically early yield components could be counterproductive as far as improving yields markedly. However, earliness tends to reduce the total plant water requirement and may increase the grain:shoot ratio. This may reduce the overall total plant production but may increase harvestable grain yield.

Ray et al. (1974) agree with Reitz and Mac Key that a crop in semi-arid regions has certain optimal seasonal growth patterns and is not under continuous moisture-stress conditions. Therefore, a crop breeder should select plants where grain producing periods match the maximum seasonal precipitation pattern. Similarly, Hurd (1974) and associates determined that 'Pelissier' durum was drought tolerant in western Canada because it had a good early root growth pattern and deep root development. They were able to transfer these traits to 'Lakota' durum. Two improved durums, 'Wakooma' and

'Wascana', resulted from this transfer. However, the deep rooting pattern so advantageous in western Canada might not be effective in other regions. Because selection for root characteristics is laborious, Hurd suggests that the best approach is to study parental germplasm thoroughly and then combine them to best advantage. Hurd lists four things breeders should look for in choosing parental material for breeding programs in semi-arid regions: "1) Extensive root system especially at lower depths. 2) Resist a decay of their photo-synthetic operation under stress. 3) Have the ability to pursue productivity under water stress. 4) Grow fast at early stages and then build up a reserve of assimilates that can be used at later stages when stress occurs."

Earliness, matching maximum plant productivity with maximum seasonal precipitation, and developing plants with extensive root growth patterns at optimum soil moisture depths are essentially drought-escaping techniques. In each case, once the optimal genotypes has been developed, no further progress can be expected in these areas. However, Hurd believes that selection for high yield under conditions of moisture stress will also select for more extensive root systems. On the other hand, some writers believe that selecting for drought tolerance and yield are incompatible. Stomate control is one mechanism for responding to moisture stress yet adequate transpiration is necessary for appropriate gas exchange and for plant cooling in periods of high temperature. Hurd reports that wheats selected for growing in moisture-stress areas have narrow leaves and low shoot-root ratios and tend to be low yielding. Dedio (1975) reported that some drought-resistant cultivars had greater resistance to dessication in cut flag leaves. Dedio also reported that 'Pitic 62' is an excellent water retainer and that this trait in crosses appears to be governed as a simply inherited dominant. Erect, dark green leaves have been suggested for increased photosynthesis yet these may provide adverse canopy temperatures. Reitz (1974) suggests that while drought tolerance and efficient water use often provide similar end results, they should not be associated too closely. He defines drought resistance as "the ability to survive, endure, compensate for or escape from damage from wilting". Water-use efficiency is determined by the dry matter production per measured quantity of water used.

Turner (1977) classifies drought resistance mechanisms into three categories: 1) drought escape; 2) drought tolerance at high water potential; and 3) drought tolerance at low water potential. He suggests that drought escaping mechanisms such as rapid and optimal phenological development and developmental plasticity should not affect yield. Reduction of water loss at high water potential through increased stomatal and cuticular resistance, reduced radiation absorption and reduced leaf area all would be expected to depress yield. Maintenance of turgor through osmotic adjustment, cell size decrease, or increase in elasticity he did not expect to lead to yield reduction. Boyer and McPherson (1975), also, state that drought avoidance or drought-avoidance

characters may be at the expense of plant productiveness. They, also, suggest that improved plant response to moisture-stress situations has been rare.

Moss et al. (1974) reported that techniques for selecting for greater water-use efficiency in plants were not available at that time, and more recent reports continue to state that such guides for selecting for specific physiological traits associated with improved water-use efficiency are not available at the practical plant breeding level. Or if they are available, plant breeders generally are not using them. Blum (1977) agrees that methods are not available for application in selection in large populations but believes that there is ample basic knowledge regarding crop response to drought situations. However, this is an area currently being explored. One of the problems is in identification of desirable genes for improved water-use efficiency. Eslick and Hockett (1974) point out that some of these genes may be in otherwise undesirable germplasm that masks their genetic effect. If they could be identified, then they could be moved into superior genotypes by backcrossing.

If selecting for phenotypic traits that promote drought resistance or avoidance is nonproductive in terms of yield increases, and selecting for greater water-use efficiency is currently not available in the practical plant breeding realm, what can the wheat breeder in the semi-arid regions do? Yield has been the final criterion for selection. Reitz (1974) said: "A breeder can ruin a population by making wrong choices based on nonproductive criteria". "He finds out he did something wrong when he sees the yield, but this is too late to tell him what he should have used as selection criteria". Unfortunately, Reitz did not identify the selection criteria.

Blum (1977) suggests two possible avenues of breeding for yield under semi-arid conditions. The first approach is to breed for superior yielding varieties at the potential level on the assumption that the top lines will also perform well under subpotential levels. Turner (1977) quotes work of Laing and Fischer that would support that approach. Blum notes, however, that it is increasingly more difficult to raise such optimum yield levels and progress via this approach may be very slow. A second approach, he suggests, would be to select under stress or drought conditions on the assumption that only those selected under such conditions will do well in adverse situations. Gotoh and Chang (with O'Toole, 1979) point out that progress from selecting under drought-stress environments may also be very slow because of the great variability in such environments. They further state that absolute yield under drought-stress conditions is not as meaningful as the proportional reduction in yield from well-watered to stressed conditions. Finlay (1968), on the basis of extensive adaptation tests, believes that yield stability over environments and yield potential are more or less independent of each other.

In visiting or corresponding with other wheat breeders, the area of desirable genotype by environment interaction or genotypic

adaptation was most often mentioned. In the United States, the U.S. Department of Agriculture and cooperating state experiment stations initiated regional nursery testing in the early 1930's. This was especially important in the semi-arid Great Plains region for it served to identify varieties that performed well over a range of environments including moisture-stress situations. These were varieties on the road to developing the ideal variety described by Finlay (1963) "as having maximum genetic potential in the highest yielding environment and maximum phenotypic stability". One-location and one-year "wonders" were and are quickly identified by this regional testing. Boyd (personal correspondence) points out that in Western Australia under a very unpredictable moisture supply,--"the result is that often the best variety, over seasons, is seldom the highest yielder in any one trial ... there is adaptive advantage in mediocrity". However, a good variety should consistently exceed the mean of the trials in which it is entered.

If a desirable genotype by environment interaction is the best selection criterion, how can we enhance it? Boyd in Western Australia selects, from adapted X introduced parent crosses, those spaced F_2 plants that fall in the optimum maturity period and have a definite tillering pattern (in his case determinant). Selected F_2 plants are bulked and yield tested as mass-selected F_3 bulks and F_4 bulks in order to obtain up to 10 season X location interactions. Welsh at Colorado State University has used a similar system although the selection criteria may be different. In his situation, he also grows each F_3 bulk for selection purposes at one location. Thus, after yield data for the other locations are available, further selection on the high yielding bulks can be performed with the representative bulk seeded for selection purposes.

At the University of Nebraska, space seeding of F_2 populations is precarious because of winter damage. Thus, we bulk seed the F_2 and F_3 populations and head select in appropriate F_3 bulks. From 45,000 to 60,000 F_4 selections, about 3,000 lines will be harvested and seeded for F_5 observation. This will be reduced to about 500 F_6 lines. Desirable genotype X environment interaction is then determined for the remaining 500 lines at three locations: Mead, elevation 330 meters, precipitation 750 millimeters; Clay Center, elevation 550 meters, precipitation 600 millimeters; Sidney, elevation 1300 meters, precipitation 450 millimeters. Although "one-year wonders" do occur, the above testing has been effective.

Lupton (1970) suggested that the F_2-derived bulk testing and selection system (similar to the F_2-derived line method of Nilsson-Ehle) might be used effectively under limited moisture conditions. In this method, seed of F_2 plant selections from phenotypically superior bulks is increased until yield testing can be done. Then further selection is restricted to the highest yielding F_2-derived lines.

Andrews (1976), of the ICRISAT Pearl Millet Breeding Program,

suggests that "multilocational breeding should precede multilocational yield testing". That is, if there is value in testing over a number of locations to determine adaptation of new genotypes, there should be equal value in determining adaptive values for very early generation material. He suggests replicating the F_2 generation in multilocations, and certainly F_3 lines derived from the better adapted multilocational F_2 nurseries should be multilocationally tested. In wheat, obtaining sufficient seed from F_2 plant selections is often a deterrent to multilocational breeding and testing. Further, testing of large numbers of lines multilocationally is expensive, and unaccessibility of distant nurseries a deterrent to adequate note taking.

Eberhart and Russell (1966) suggested that when multilocational testing was not feasible, "extra locations" at one site could be produced artificially by planting dates, differential fertility applications, and moisture additions. Hanks et al. (1976) suggest using line sprinklers to supply a continuous water gradient irrigation system for studying genotype by moisture level interaction at one location. Conversely, precipitation can be limited by use of plastic or fiberglass covering above the growing crop or by placing plastic sheets or rain gutters between rows in order to reduce or limit the amount of rainfall available to the growing crop.

Finally, something should be mentioned regarding the generation of selection. At Nebraska we select mostly in the F_3 generation. Many F_3-derived lines are surprisingly uniform. There is no evidence to support the idea that phenotypically highly uniform varieties perform best--certainly not in highly variable semi-arid regions. Further, phenotypic uniformity does not insure genetic uniformity anyway. We select in the F_3 for two basic reasons: 1) it is financially cheaper for us to select only once in any population; 2) if we select just one, the F_3 generation, we believe, is the optimum one since (a) it is a compromise betweeen having a derived population with the largest number of favorable factors (homozygous or heterozygous, Shebeski and Evans, 1973) and possible uniformity, and (b) provides population buffering (Allard and Bradshaw, 1964) in our variable Great Plains climate.

In summary, it appears that until techniques are developed that will allow for identification of and selection for improved water-use efficiency, breeding systems should select maturities and growth patterns most closely attuned to seasonal moisture availability and exploit methods for detecting the most desirable genotype X environment interactions of their materials at the earliest possible breeding stage. Careful choice of parental material which can be more thoroughly studied than large segregating populations is indicated.

Literature Cited

Allard, R. W. and A. D. Bradshaw. 1964. Implications of genotype-environment interactions in applied plant breeding. Crop Sci. 4: 503-507.

Andrews, D. J. 1976. Multilocational breeding. Paper read at the All-Indian Co-ordinated Millets Improvement Project Annual Workshop. Gwalior, India. (by permission)

Blum, A. 1977. Genetic improvement of drought resistance in crop plants. p. 429-445. In Mussell, H. W. and R. C. Staples (eds.) Stress Physiology in Crop Plants. Wiley Interscience, New York.

Boyd, W. J. R. 1980. Personal correspondence.

Boyer, J. S. and H. G. McPherson. 1975. Physiology of water deficits in cereal crops. Advances in Agronomy 27:1-23. Acad. Press, Inc., New York.

Dedio, W. 1975. Water relations in wheat leaves as screening tests for drought resistance. Can. J. Plant Sci. 55:369-378.

Eberhart, S. A. and W. A. Russell. 1966. Stability parameters for comparing varieties. Crop Sci. 6:36-40.

Eslick, R. F. and E. A. Hockett. 1974. Genetic engineering as a key to water-use efficiency. Agric. Meteorol. 14:13-23.

Finlay, K. W. 1963. Adaptation--its measurement and significance in barley breeding. Barley Genetics I. p. 351-359. First Intern. Barley Genet. Symp. Wageningen 1963. Pudoc, Wageningen, The Netherlands.

Finlay, K. W. 1968. The significance of adaptation in wheat breeding. p. 403-409. Proc. Third Intern. Wheat Genet. Symp. Canberra, Australia.

Gotoh, K. and T. T. Chang (with sectional collaborator J. C. O'Toole). 1979. Crop adaptation. p. 234-261. In J. Sneep and A. J. T. Hendriksen (eds.) and O. Holbek (co-ed.) Plant Breeding Perspectives. Center for Agric. Publ. and Docum. Wageningen, The Netherlands.

Hanks, R. J., J. Keller, V. P. Rasmussen, and G. D. Wilson. 1976. Line source sprinkler for continuous irrigation--crop production studies. Soil Sci. Soc. of Am. J. 40:426-429.

Hurd, E. A. 1974. Phenotype and drought tolerances in wheat. Agric. Meteorol. 14:39-55.

Lupton, F. G. H. 1970. Testing and selection procedures in early generations of wheat crosses. Proc. Third FAO/Rockefeller Foundation Wheat Seminar. p. 178-182. Ankara, Turkey. FAO Org. of the United Nations.

Mac Key, J. 1970. An ecological model for yield in small grains. Seminar Series, p. 128-149. Dept. Agron., Iowa State Univ., Ames, Iowa. (by permission)

Moss, D. N., J. T. Woolley, and J. F. Stone. 1974. Plant modification for more efficient water use: The Challenge. Agric. Meteorol. 14:311-320.

Ray, L. L., C. W. Wendt, B. Roark, and J. E. Quisenberry. 1974. Genetic modification of cotton plants for more efficient water use. Agric. Meteorol. 14:31-38.

Reitz, L. P. 1974. Breeding for more efficient water use--is it real or a mirage. Agric. Meteorol. 14:3-11.

Shebeski, L. H. and L. E. Evans. 1973. Early-generation selection for wide-range adaptability in the breeding program. Proc. Fourth Intern. Wheat Genetics Symp. p. 587-593. Columbia, Missouri.

Turner, N. C. 1977. Drought resistance and adaptation to water deficits in crop plants. p. 343-372. In Mussell, H. W. and R. C. Staples (eds.) Stress Physiology in Crop Plants. Wiley Interscience, New York.

Additional References

Hurd, E. A. 1976. Plant breeding for drought resistance. In T. T. Kozlowski (ed.) Water Deficits and Plant Growth. Vol. IV, p. 317-383. Acad. Press, New York.

Proceedings: Fourth Regional Winter Cereal Workshop. 1978. Barley (Vol. II). 420 p. ICARDA, Aleppo, Syria, and CIMMYT, El Batan, Mexico.

GENOTYPE x ENVIRONMENT INTERACTIONS FOR LEAF AREA PARAMETERS AND YIELD COMPONENTS AND THEIR EFFECTS ON WHEAT YIELDS

S. Borojevic and W. A. Williams
Yugoslavia and USA

Abstract

Genotype x environment interactions for some parameters characterizing to source capacity and sink capacity and their effects on grain yield of three divergent wheat cultivars were studied over a 10-year period in one location.

The variance in the number of spikes/m^2 due to genotype x year interaction (g x y) was greater than the variances due to years or genotypes alone. The variance for leaf area index (LAI) and leaf area duration (LAD) due to years was greater than the variances due to genotypes and g x y interactions. The variances due to genotypes were greater than the variances for years and g x y interactions for number of kernels/spike, thousand kernel weight, disease and lodging resistance, as well as for grain yield. Environmental factors exhibited greater effect on the parameters of source capacity than on the parameters of sink capacity.

Leaf area duration (LAD) showed the highest positive relative contribution to grain yield for each cultivar over a 10-year period. Direct effects of other variables were different for almost each cultivar; some exhibited positive and some negative direct effects on grain yield. Using seven variables, 83% of variation of grain yield could be explained for Sava, 75% for Bezostaia, but only 34% for Bankut, as shown by the coefficient of determination.

Temperature, rainfall and sunshine varied so much among the years that actually neither a single year approximated the average year nor a single parameter approximated the average 10-year value. The only significant positive association was found between grain yield and hours of sunshine in May and June, i.e., during gamete formation, fertilization, and grain filling period.

Bezostaia showed the greatest stability in yield performance, but Sava gave the highest grain yield in all years. Since a producer is interested in having high grain yields at his location, the preference in the choice of cultivars should be given to the mean grain yield rather than to the other stability parameters.

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University of Novi Sad and University of California-Davis.

Introduction

Studies of genotype x environment interactions for yield are intended to show the magnitude of genotype x location versus genotype x year interactions (Allard and Bradshaw, 1964). They are aimed at the determination of general (wide) and specific (narrow) adaptability as well as stability parameters for grain yield (Finlay and Wilkinson 1963, Eberhart and Russell 1966, Baker 1969, Martinic 1973, Borojevic 1975) or at the finding of suitable criteria for selection of superior genotypes for a particular environment (Brennan and Byth, 1979).

It is generally accepted that genotypes with wide adaptability have lower yield potential while genotypes with narrow adaptability have higher yield potential (Finlay and Wilkinson, 1963). However, it should be emphasized that the breeding of new high-yielding cultivars, together with advancement in agricultural practices, shows that cultivars with high genetic potential for yield can also have wide adaptability. Examples are the cultivars Bezostaia and Sava (Borojevic, 1975), Talent, Yubiley, Partizanka and others in the IWWPN (Wilhelmi et al., 1976, 1978, 1979). The finding of Brennan and Byth (1979) that the performance in higher-yielding environments provided better prediction of line performance across environments than that from lower-yielding environments, is particularly worthy of consideration.

Information on adaptability and performance stability of a cultivar over years and locations is important for national policy in crop production, but a producer is interested in growing a cultivar with high yield and performance stability at his location.

To test these views, three winter wheat cultivars leading in production for three successive periods were evaluated in a 10-year experiment at one location. The objectives of the study were to determine genotype x year interactions for some parameters characterizing to source capacity and sink capacity as well as to evaluate their effects on grain yield.

Material and Methods

The cultivars chosen for the study were: 1. Bankut-1205, tall straw, winterhardy, midlate, leading cultivar in the Pannonian Plain of Yugoslavia from 1945 to 1981, 2. Bezostaia-1, short straw, winterhardy, midlate, leading cultivar from 1965 to 1974, 3. Sava, semidwarf, medium winterhardy, midearly, leading cultivar from 1974 to 1979.

More information on the characteristics of these cultivars may be found elsewhere (Borojevic, et al., 1980).

Experiments were conducted in Novi Sad for 10 years (1967/68-1976/77) in a randomized block design with 3 replicates, the basic

plot being 5 m^2. The planting rate was 600 seeds/m^2 and the plants were grown in an intensive agricultural practice, including 150 kg/ha of applied nitrogen.

Green area data were obtained on the basis of 15 plants in 3 replicates. Leaf area index (LAI) includes all green parts of leaves and stem, except spike. Leaf area duration (LAD) is computed from LAI x days summed from flowering to complete senescence of green parts.

To estimate genotype x environment interactions and stability of yield, analyses of variance and regression were used. To evaluate the relative contribution of independent variables to grain yield, ridge regression and path-coefficient analyses were applied (Dewey and Lu 1959, Jeffery and McKinney 1975, Williams et al., 1979). To overcome the difficulty in estimating regression coefficients due to multicollinearity of independent variables standard partial regression coefficients for bias factor k=0.05 were chosen based on inspection of the ridge traces to keep the values of variance inflation factors less than 10, and were considered to be the path coefficients here.

Results

Genetic differences, variances and genotype x environment interactions--The number of culms or spikes/m^2 is considered to be the first and most important yield component. In this 10-year experiment, cultivars on the average produced about the same number of spikes/m^2 (Table 1), which assured an equal background for environmental factors to act and genetic differences to be expressed.

The variation in the number of spikes/m^2 was greatest for Bankut and smallest for Sava (Table 1). The variance due to genotype x year interaction (g x y) was much higher than the variances due to the effect of years and genotypes (Table 2).

High g x y interaction for the number of spikes/m^2 resulted from varying ability of cultivars to adjust their canopy to the enviornment as a consequence of genetic differences in culm length, resistance to lodging (Table 1), tillering capacity, type of crown, and leaf architecture. Bankut developed more spikes/m^2 than Sava in favorable years, while Sava, due to its open crown and an even distribution of culms in space, had the ability to develop more spikes in unfavorable years.

For leaf area index (LAI), differences between cultivars were not significant (if we take LSD values for g x y, Table 1). Even though Bankut has a longer culm it showed faster senescence of lower leaves due to their planophile position and early lodging, and consequently, even smaller LAI at the flowering stage than the other two cultivars (Table 1).

The effect of years was larger on LAI than on any other parameter studied, its variance being more than ten times greater than the variances due to genotypes and g x y interactions (Table 2).

Table 1. Ten-year averages and variation ranges of some attributes and grain yield of winter wheat cultivars grown in Novi Sad (Yugoslavia) (1967/68-1976/77).

Cultivar	Culm height (cm)	Leaf area index in n^2/m^2 (LAI)	Leaf area duration in days (LAD)	No. spikes per m^2 (SPM)	No. kernels per spike (KERSP)	1000 kernels weight in g (TKWT)	Resist. to *Puc.r.* & *E.gram.* (DISRES)	Resist. to lodging (LODGRES)	Grain yield (t/ha)
Bankut-1205	113.6 (106-122)*	6.77 (3.7-9.6)	155 (86-226)	675 (441-931)	19.5 (16-23)	36.7 (31-42)	5.1** (3-6)	1.8** (1-3)	4.43 (3.4-5.7)
Bezostaia-1	91.2 (87-95)	7.00 (3.6-9.9)	164 (88-271)Y	634 (406-839)	23.4 (19-25)	40.4 (35-45)	5.8 (4-7)	5.0 (1-9)	5.55 (3.9-7.1)
Sava	82.4 (77-91)	7.47 (3.1-11.9)	191 (75-299)	688 (456-878)	28.0 (23-32)	33.3 (26-37)	6.6 (5-8)	7.1 (3-9)	6.30 (4.8-8.6)
LSD of g x y for 5%	2.98	0.86	12.8	87	2.11	1.58	0.84	0.94	0.455
1%	3.94	1.14	17.1	116	2.68	2.10	1.12	1.25	0.606

*Numbers in parantheses refer to variation range for that character during 10-year period.
** 1 = low resistance (susceptible), 9 = high resistance.

Table 2. Variances of different variables influencing grain yield in 3 wheat cultivars over a ten-year period.

Source of variation	Variances for								
	DF	LAI	LAD	SPM	KERSP	TKWT	DISRES	LODGRES	Grain yield y
Blocks	2	0.17	118.5	1244.0	6.09	1.47	0.28	0.30	2036.1
Genotypes - g	2	3.93	10464.0	24537.1	1176.00	377.96	16.88	211.63	265719.0
Years - y	9	55.29	34828.2	42503.7	81.25	85.20	7.22	20.69	118987.0
Interaction g x y	18	2.46	1798.9	88003.8	12.40	9.67	1.47	3.30	7316.2
Error	58	0.28	61.7	2859.6	3.41	0.95	0.27	0.33	778.2
Total	89								

In contrast to LAI, varietal differences in leaf area duration (LAD) were highly significant (Table 1). This shows that LAD is not only dependent on LAI with which it is highly correlated (Table 4), but, in addition, includes varietal differences in longevity of green parts, resistance to diseases, leaf laminae architecture, etc. This is also confirmed by a larger genotypic variance for LAD than for LAI in relation to variances due to years and g x y interactions (Table 2). Bankut showed the smallest variability and the lowest mean value for LAD, Sava the opposite.

In the number of kernels/spike varietal differences were highly significant (Table 1), as shown also by a high variance due to genotype compared with the variances due to the effect of years and g x y interaction (Table 2).

Thousand kernel weight was highest for Bezostaia and lowest for Sava (Table 1). Variance due to genotypes was much higher than the variances due to year and g x y interaction (Table 2).

The cultivars examined were screened for two major diseases in the region, i.e., leaf rust and powdery mildew. Sava showed a rather good field resistance to both diseases; Bezostaia was resistant to leaf rust but susceptible to powdery mildew, and Bankut vice versa (Table 1).

For the resistance to lodging, differences between cultivars were highly significant (Table 1) and the variance due to genotypes was much higher than that due to years and g x y interaction (Table 2).

Highly significant differences between cultivars were found for grain yield (Table 1). This also is supported by the variance due to genotypes which was twice as high as the variance due to effect of years and several times higher than the variance due to g x y interaction (Table 2).

Relative contribution of leaf area parameters and yield components to grain yield.--Seven independent variables versus grain yield (dependent variable) were chosen for path-coefficient analysis after computing the ridge traces to evaluate the relative contribution of source and sink capacity parameters to grain yield. Path-coef. analysis revealed that leaf area duration (LAD) had the greatest positive direct effect on grain yield (P_{2Y}) for each cultivar and for the 10-year period, and this also was in full agreement with the simple coefficient of correlation (r_{2Y}) (Table 3). Direct effects of other variables on grain yield were different for each cultivar.

The direct effect of leaf area index (LAI) on grain yield (P_{1y}) was positive but small for Bankut, negative and small for Benzostaia and strongly negative for Sava (Table 3). This, however, could not be detected by simple coefficients of correlation (r1Y), which were significantly positive, a result of a strong positive indirect effect via LAD.

Number of spikes/m^2 (SPM) exhibited a strong positive direct effect on the grain yield of Sava, but a small and negative effect for Bankut and Bezostaia (Table 3). A positive simple coefficient of correlation came via a strong positive indirect effect of LAD, which in turn is highly positively correlated with SPM (Table 4).

The relative contribution of the number of kernels/spike (KERSP) to grain yield (P4Y) was sizable for Bezostaia and Sava, but small and negative for Bankut. This was in rather good agreement with the simple coefficient of correlation (r4Y) (Table 3).

Thousand-kernel weight (TKWT) contributed differently to grain yield(P5Y) for each cultivar. It showed a sizeable positive direct effect in Bezostaia, sizable negative effect in Bankut, and a small positive effect in Sava, which was in agreement with r5Y only for Bezostaia (Table 3).

Resistance to diseases (DISRES) showed a sizable positive direct effect on grain yield (P6Y) for Bankut but a negative one for Bezostaia and Sava, which was in rather good agreement with r6Y (Table 3).

Resistance to lodging (LODGRES) exhibited a sizable positive direct effect on grain yield (P7Y) for Sava and the 10-year period but not for the other two cultivars (Table 3).

The effect of climatic factors on grain yield.--The effect of environmental factors is shown through variances for years and genotype x year interactions (Table 2). This is a joint effect of environmental factors including the effect of climatic factors, soil preparation, response to fertilizers etc. Testing the effect of a single climatic factor on grain yield showed an interesting picture.

Mean air temperatures showed a positive effect on grain yield, but it was not significant (due to the small number of pairs, Table 5). Absolute minimum temperatures that occurred in January (I) or February (II) showed a positive effect on grain yield for Bezostaia and Sava, which are less winterhardy, than for Bankut (Table 5). This looks rather contradictory but it could be explained by the fact that lower temperatures, like -20.8°C in 1968 or -23.6°C in 1969 were accompanied by snow cover and thus less damaging than -13.8°C in 1972 or -10.8°C in 1975 without snow cover (Table 5). Absolute maximum temperatures in May (V) and June (VI), in the flowering and grain filling period, were not too high and there was no effect on grain yield (Table 5).

Rainfall during the vegetative period from October (X) through the end of June (VI) showed a small negative effect on grain yield (Table 5). This was due to excessive rainfalls in June of 1969, 1970, 1973 and 1975 (Fig. 1).

Of all climatic factors tested, the hours of sunshine in May and June, when the formation of gametes, fertilization and grain filling take place, showed a significant positive association with grain yield for each cultivar and for all cultivars together (Table 5).

Table 3. Path-coefficients (P, direct effect only) and simple coefficients of correlation (r) of variables influencing grain yield in 3 wheat cultivars over a 10-year period.

Variables	Bankut-1205 N-30	Bezo-staia-1 n-30	Sava n-30	All cv. n-90
1. Leaf area index-LAI vs. grain yield-y				
Direct effect P_{1y}	0.196	-0.168	-0.710	-0.290
Simple coef. correlation r_{1y}	0.454*	0.618**	0.390*	0.453**
2. Leaf area duration-LAD vs. y				
Direct effect P_{2y}	0.442	0.684	0.519	0.623
Simple coef. cor. r_{2y}	0.515**	0.660**	0.585**	0.594**
3. Number of spikes/m^2-SPM vs. y				
Direct effect P_{3y}	-0.113	-0.096	0.657	0.174
Simple coef. cor. r_{3y}	0.353	0.517**	0.563**	0.397**
4. Number of kernels/spike KERSP vs. y				
Direct effect P_{4y}	-0.166	0.227	0.304	0.294
Simple coef. cor. r_{4y}	0.141	0.231	0.405*	0.554**
5. 1000 kernel weight-TKWT vs. y				
Direct effect P_{5y}	-0.232	0.414	0.132	0.198
Simple coef. cor. r_{5y}	-0.067	0.368*	0.546**	0.062
6. Resistance to diseases-DISRES vs. y				
Direct effect P_{6y}	0.272	-0.473	-0.123	-0.177
Simple coef. cor. r_{6y}	0.132	-0.293	0.131	0.218
7. Resistance to lodging-LODGRES vs. y				
Direct effect P_{7y}	0.040	0.057	0.342	0.409
Simple coef. cor. r_{7y}	-0.041	0.030	0.262	0.481**
Coef. of determination R^2	0.345	0.746	0.833	0.713

Table 4. Simple coefficients of correlation between green area parameters, yield components and grain yield for 3 wheat cultivars over a 10-year period.

Cultivars and variables	LAD x_2	SPM x_3	KERSP x_4	TKWT x_5	DISRES x_6	LODGRES x_7
Bankut-1205 (n=30)						
x_1- Leaf area index - LAI	0.899**	0.902**	0.340	-0.297	-0.146	-0.282
x_2- Leaf area duration - LAD		0.723**	0.220	-0.085	0.015	-0.218
x_3- No. spikes/m^2 - SPM			0.374*	-0.333	-0.141	-0.329
x_4- No. kernels/spike - KERSP				-0.505**	0.259	-0.218
x_5- 1000 kernel weight - TKWT					0.454**	0.383*
x_6- Disease resistance - DISRES						0.316
Bezostaia-1 (n=30)						
x_1- LAI	0.915**	0.911**	0.490**	0.167	-0.201	-0.414*
x_2- LAD		0.788**	0.496**	0.280	-0.002	-0.346
x_3- SPM			0.312	0.285	-0.139	-0.425*
x_4- KERSP				-0.317	0.106	-0.325
x_5- TKWT					0.278	0.320
x_6- DISRES						-0.072
Sava (n=30)						
x_1- LAI	0.909**	0.936**	0.582**	0.140	0.402*	0.382*
x_2- LAD		0.927**	0.712**	0.260	0.390*	-0.332
x_3- SPM			0.536**	0.259	0.372*	-0.220
x_4- KERSP				-0.104	0.256	-0.458**
x_5- TKWT					0.059	0.577**
x_6- DISRES						0.013
10 years x 3 cult. x 3 rep.=90						
x_1- LAI	0.903**	0.883**	0.381**	-0.029	0.123	-0.139
x_2- LAD		0.779**	0.501**	0.016	0.263*	-0.016
x_3- SPM			0.287**	-0.052	0.039	-0.179
x_4- KERSP				-0.485**	0.495**	0.469**
x_5- TKWT					0.021	0.003
x_6- DISRES						0.395**

Table 5. Climatological data during winter wheat growing season in Novi Sad, latitude 45°5'N, longitude 19°8'.

Year	Temperature in °C			Rain fall in mm	Hours sunshine during months		Grain yield in t/ha
	Mean air XI-VI months	Aps. min. I or II	Aps. max. V or VI	X-VI	XI-VI	V & VI	
1967/68	8.4	-20.8	34.6	290	1222	503	4.25
1968/69	6.9	-23.6	34.0	436	1002	480	4.58
1969/70	7.2	-17.8	31.0	582	948	426	3.97
1970/71	8.1	-17.2	31.2	354	1162	544	6.64
1971/72	8.9	-13.8	33.1	327	1164	496	6.43
1972/73	7.8	-12.5	33.3	427	1080	510	6.92
1973/74	7.8	-14.6	31.2	399	1165	412	4.65
1974/75	8.6	-10.8	31.1	403	1159	423	4.67
1975/76	6.8	-18.1	30.5	347	1221	502	6.21
1976/77	9.3	-14.1	32.4	486	1220	516	6.22
Grand mean	8.0	-15.1	32.2	405	1134	481	5.43
Correlation with yield	0.223	0.343	-0.059	-0.263	0.356	0.727*	5.43
Bankut-1205	0.406	0.026	0.094	-0.190	0.175	0.725*	4.43
Benzostaia-1	0.253	0.391	-0.063	-0.295	0.460	0.723*	5.55
Sava	0.156	0.392	-0.089	-0.257	0.351	0.682*	6.30

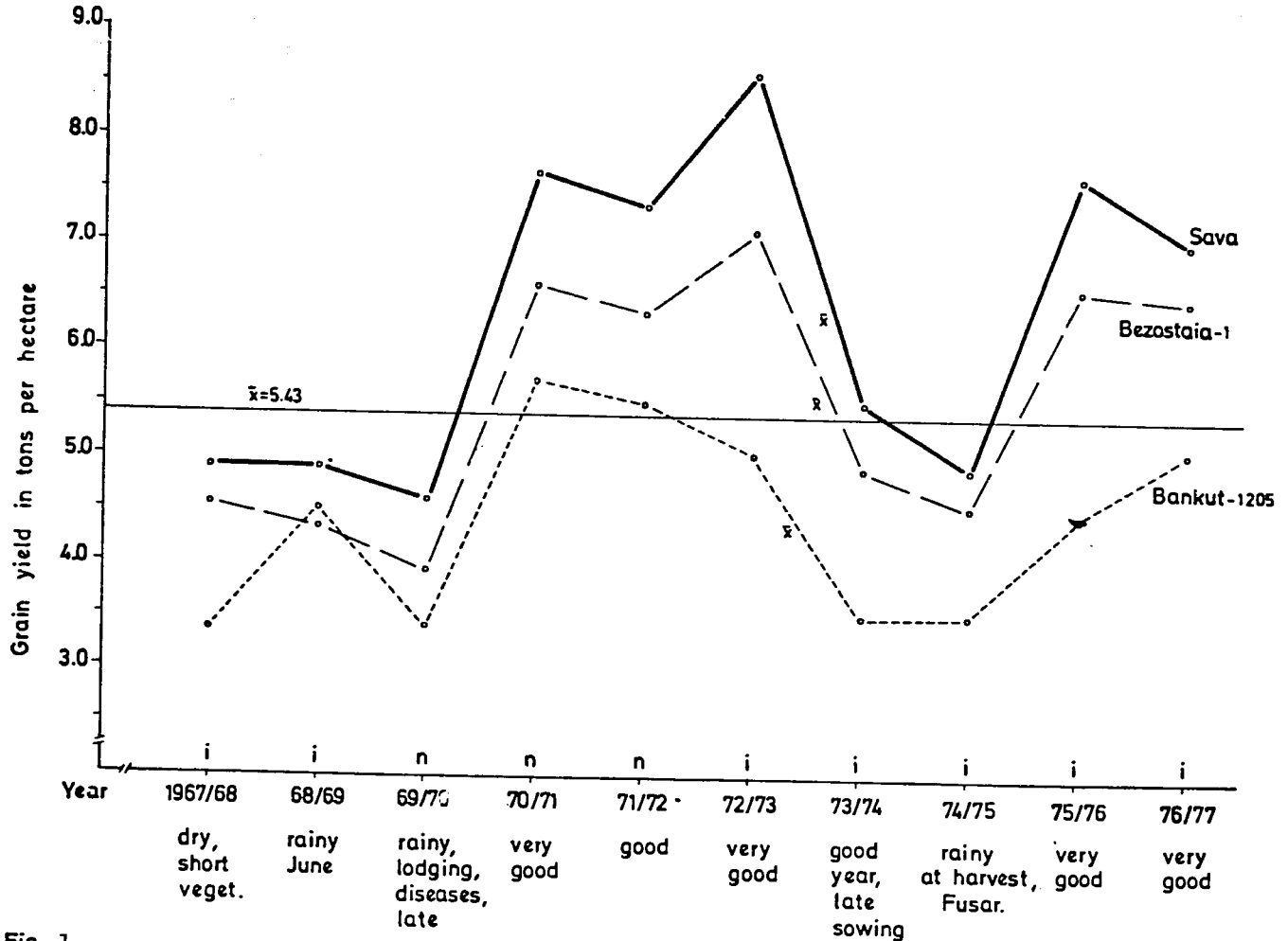


Fig. 1.
Effect of main environmental factors on variation of grain yield in 3 wheat cultivars.

When stability of grain yield over the 10-year period was analysed, Bezostaia was the most stable in yield performance, but Sava consistently produced higher yields, particularly in favorable years (Fig. 2).

Discussion

Genotype x year interactions for all studied parameters were significant, but variances were much smaller than for genotypes and years except for the number of spikes/m^2 (Table 2). The number of culms or spikes per unit area is primarily affected by the environment and can be regulated by agricultural practices (rate and date of sowing, etc.). Therefore, it was expected that the effect of years would be greater than the effect of genotypes. If differences among genotypes in tillering capacity and/or winter resistance do exist, as was the case in our experiment, genotype x year interaction for the number of culms or spikes/m^2 may be high.

Culms per unit area serve as an axis on which parameters of source capacity (LAI, LAD etc.) and sink capacity (KERSP, TKWT, etc.) develop and function. Therefore, it is essential to have an optimum density for each genotype. When the number of spikes/m^2 exceeds the optimum, as happened for Bankut and in some years for Bezostaia, its direct effect on grain yield may even be negative. Cultivar Sava with semi-dwarf stature and high resistance to lodging could withstand even higher density, and therefore the direct effect of SPM on grain yield was strongly positive (Table 3). Even though the number of spikes/m^2 is highly positively correlated with both LAI and LAD (Table 4), each of these parameters exhibited different direct effects on grain yield. (Table 3).

A negative direct effect of LAI on grain yield was also observed in two other sets of experiments with 8 wheat cultivars (Borojevic et al., 1980). It seems plausible that such an effect can be explained by a state of disharmony between the growth of vegetative parts and the growth of reporductive parts of plant. When environmental factors (abundant rain, much nitrogen, less sunshine, etc.) favor the growth of culms and leaves, large LAI will develop. If, during the fertilization and grain filling period, environmental conditions become unfavorable (lodging, drought, etc.), much of photo-assimilates will be used for maintenance of green parts instead of being translocated into the grain. This situation occurred in half of the ten experimental years when the LAI of Bankut and Bezostaia contributed relatively little to grain yield. On the other hand, for Sava, which in 1967/68 and 1968/69 developed smaller LAI than other two cultivars and in the last four years (1973/74 to 1976/77) too large a LAI. LAI had a strong negative direct effect on grain yield on the average. However, this could not be seen from the simple coefficient of correlation due to strong positive indirect effects via LAD and SPM (Tables 3 and 4).

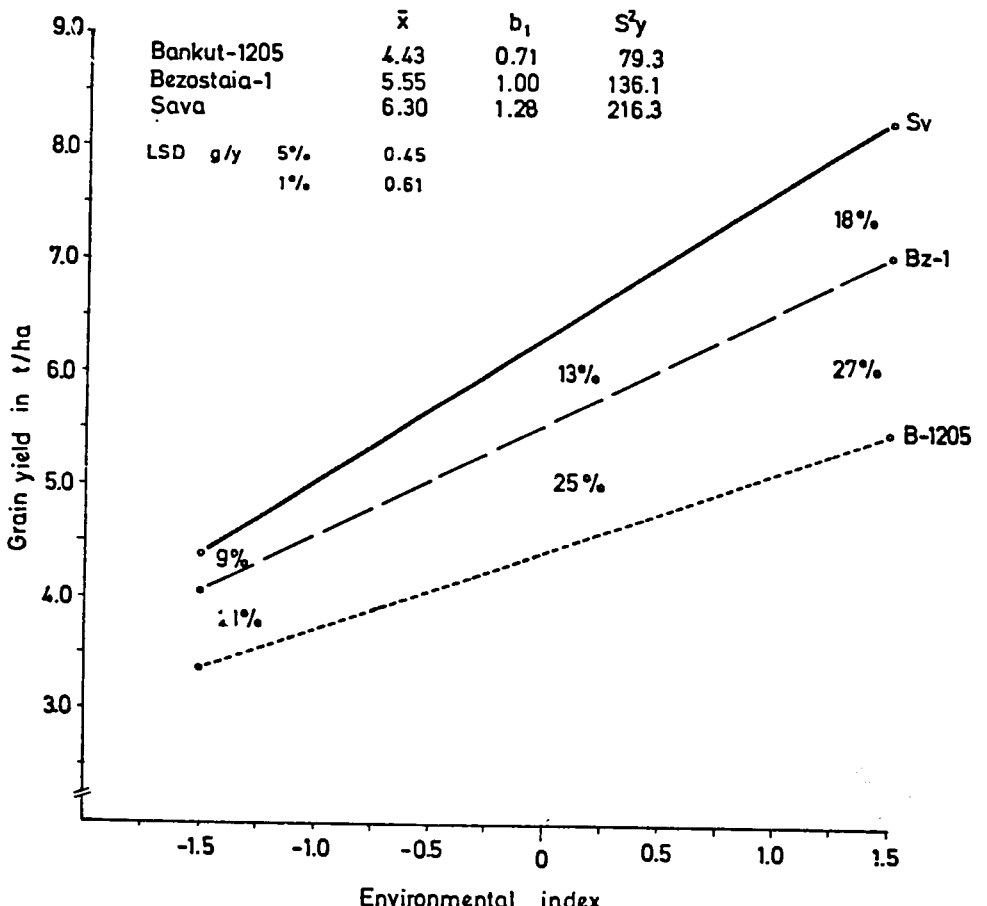


Fig. 2. Regression of grain yield on environmental index over a 10-year period

Conversely, LAD always exhibited a strong positive direct effect and made a considerable relative contribution to grain yield. This clearly demonstrates the importance of the duration of photosynthetic activity for grain yield formation. It also indicates that in prolongation of LAD and the grain-filling period, in accordance with agroecological factors, further increase in genetic potential for yield may be sought. This highly positive effect of LAD was certainly associated with the amount of sunshine during the grain filling period which in turn showed a significant positive correlation with grain yield (Table 5).

The effect of disease resistance on grain yield was not as one would expect. It was probably expressed through LAD since the more resistant plants had a larger green area and longer photosynthetic activity. Besides, the effect of DISRES was counteracted by lodging. Therefore, a direct effect of DISRES on grain yield was not possible to differentiate even by the path-coefficient analysis.

A positive direct effect of LODGRES can be seen only from all-cultivars data. If a cultivar lodges every year, as was the case with Bankut, or possesses medium resistance like Bezostaia, then the contribution of resistance to lodging to grain yield cannot be expressed. If a cultivar possesses a good resistance and lodges only in some years (the case with Sava), then the contribution of LODGRES to grain yield may be quite sizable (Table 1 and 3).

The seven parameters or variables evaluated for their relative contribution to the grain yield could not explain all variations in grain yield, as shown by the coefficient of determination (R^2). For Sava, 83% of variation could be explained, for Bezostaia 75%, and for Bankut only 34% (Table 3). By using ridge regression, it was possible to choose "the best" regression, since it was found that only five variables (LAI, LAD, SPM, KERSP and TKWT) explain 79%, 53% and 29% of variation in the yields of the respective cultivars. The introduction of the two variables DISRES and LODGRES increased considerably the percentage for Bezostaia, but did not help much in the interpretation of yield variation for Bankut. If a character is completely positive or negative across environments, its contribution to grain yield cannot be seen. When different genotypes are tested or a character responds differently across environments, then its relative contribution to grain yield can be evaluated.

Since a producer is interested in growing "the best" cultivar at his location, the mean value for grain yield over years is the most important of all stability parameters for making the decision as to which cultivar to choose.

References

Allard, R. W. and A. D. Bradshaw. 1964. Implications of genotype x environmental interactions in applied plant breeding. Crop Sci. 4:503-508.

Baker, R. J. 1969. Genotype-environment interactions in yield of wheat. Can. J. Plant Sci. 49:743-751.

Borojevic, S. 1975. Ideotypes for high productivity performance stability and adaptation. Proc. 2nd Inter. Wheat Conf. Zagreb, pp.46-59.

Borojevic, S., T. Cupina and M. Krsmanovic. 1980. Green area parameters in relation to grain yield of different wheat genotypes. Zeit. fur Pflanzenzuchtung, 84:264-283.

Brennan, P. S. and D. E. Byth. 1979. Genotype x environmental interactions for wheat yields and selection for widely adapted wheat genotypes. Aust. J. Agric. Res. 30:221-232.

Dewey, D. R. and K. H. Lu. 1959. A correlation and path coefficient analysis of components of crested wheat grass see production. Agron. J. 51:515-518.

Eberhart, S. A. and W. A. Russell. 1966. Stability parameters for comparing varietes. Crop Sci. 6:36-40.

Finlay, K. W. and G. M. Wilkinson. 1963. The analysis of adaptation in plant breeding programme. Austr. J. Agric. Res. 14:742-754.

Jeffery, H. and G. T. McKinney. 1975. Application of ridge regression to agricultural data. J. Australain Int. Agric. Sci. 35:34-39.

Martinic, A. 1973. Wide-general vs. narrow-specific adaptation of common-wheat varieties. Proc. 4th Inter. Wheat Genetics Symp. Missouri Agr. Exp. Sta. Columbia, 561-563.

Wilhelmi, K. D., S. L. Kuhr, V. A. Johnson, P. J. Mattern and J. W. Schmidt. Results of the International Winter Wheat Performance Nursery in 1974, 1976 and 1977. Research Bull. 279 (1976), 285 (1978), 288 (1979). Agr. Exp. Sta. Univ. Nebraska, Lincoln USA.

Williams, W. A., C. O. Qualset and S. Geng. Ridge regression for extracting soybean yield factors. Crop Sci. 19:869-873.

UNORTHODOX METHODS OF WHEAT BREEDING

E. Sanchez-Monge
Spain

Starting to prepare the notes for this talk a question arose immediately. What is unorthodox? Where to draw the line between orthodox and unorthodox?

My impression is that the separation line will be in different positions according to place and time. There are places that would consider routine certain methods regarded as unorthodox in other places. For instance, the use of multiline wheat varieties here in Spain would be not only unorthodox, but also illegal from the point of view of seed certification.

Time also will change the position of the separation line between orthodox and unorthodox. When more than 30 years ago I started to work in cereal breeding some of the methods actually used such as chromosome substitution would have been considered highly unorthodox.

Then a starting point must be that of the relativity of the meaning of the word unorthodox.

Another starting point is offered by the Vavilov's "law of homologous variation" that, when applied to plant genetic variation, allows us to expect that if a certain type of variation is found in a given plant species, the same type of variation will be found in other species phyllogenetically related to the former one. Expanding Vavilov's law to the field of plant breeding it can be said that, after the discovery of a new unorthodox method for breeding a plant species, we can expect to adapt this method to other plant species and, in our case, to wheat breeding.

We must also bear in mind that, although there is still a great deal to do in wheat breeding through orthodox methods in many places, some authors have the opinion that we are reaching the limit in the improvement of wheat yield. Therefore, the research directed towards the discovery of more sophisticated, less orthodox methods of wheat breeding will help in the task of breaking the productivity ceiling.

My intention here is to try to give you a panoramic view of possibilities that you yourselves can classify as more or less unorthodox.

Acceleration of generations.--By the use of vernalization and greenhouses with temperature and light regulation we can obtain, at least under Spanish climatic conditions, 3-3.5 generations of wheat per year. As many as 6 generations of spring wheat and 4.5 generations of winter wheat can be obtained according to Mukade (1978) with his methods of green-vernalization and seed-green vernalization.

Escuela T.S. Ingenieros Agronomos Universidad Politecnica, Madrid.

New plant models.--Morphological modification of the wheat plant has been directed in the last years towards a reduction in culm length accompanied by increased lodging resistance under heavy nitrogen fertilization. This also has been accompanied in many cases by a greater ability of the plant to utilize a larger amount of assimilates in the production of ear primordia and a lesser amount in culm production thus improving harvest index.

Leaf morphology also has been modified towards shorter, broader, thicker and more erect leaves compounding a canopy with a low extinction coefficient for visible light and maximum energy capture by the greatest possible area of leaves (Davies, 1977).

The optimum number of tillers has been a matter of controversy. Uniculm genotypes eliminate totally non-productive stems and avoid the wastage involved in their production and competition. It is within reason to assume that each plant in a uniculm wheat population could reach more easily its full potential in terms of ear development. The inconvenience could be the necessary increase in sowing density and the danger of poor stands in years with unfavorable conditions for seed germination or seedling emergence. If you allow me a personal opinion, I think that it is possible that the optimal models will have few tillers of the same length and all capable of surviving to produce ears.

Another modification desired by wheat breeders is an increase in leaf area, as mentioned before, especially the flag leaf area since this leaf and the ear are the principal sources of photosynthate for the sinks in the seed.

The increase in ear size and its components -- number of spikelets per ear and number of seeds per spikelet, and also the increase in seed weight have limiting factors and interrelationships not fully understood.

Regarding the disjunctive bearded-beardless the only indication that seems well based is that the beards are useful for hot dry conditions.

Aneuploidy.--For many laboratories and wheat breeding centers the use of aneuploids in wheat breeding is no more an unorthodox method. However, there are other centers in which the utilization of monosomics, telosomics, addition and substitution lines (Sutka, 1979) is still unorthodox for reaching objectives such as: intraspecific chromosome substitution; interspecific chromosome substitution (with chromosomes of *Aegilops*, *Agropyron*, *Secale*, *Haynaldia* and *Hordeum* species); insertion into the wheat chromosomes of chromosome segments of other species (chromosome grafting) by means of irradiation, elimination of the chromosome 5B or supression of its action.

Hybrid wheat.--We can perhaps consider today as not very orthodox the attempt of obtaining hybrid wheat. To my knowledge, there is not yet any hybrid seed marketed on a commercial scale.

The conditions for obtaining hybrid seed in a self-fertilized plant are: 1) a genetic system for emasculation that produces male-sterile plants without reduction of female fertility, 2) easy multiplication of the male-sterile types to be used as seed parents for the hybrid seed, 3) availability of fertility restorers, 4) easy pollination of male-sterile plants with restorer pollen under field conditions for the production of hybrid seed and obtaining economically satisfactory yields, 5) restoration not influenced by environmental variability, 6) heterotic response in the hybrid "male-sterile x restorer", 7) increase in yield due to heterosis that compensates the additional cost of the hybrid seed.

In common wheat we have available systems of cytoplasmic male-sterility, we have found restorers and there are many instances of heterotic response (Auriau et al., 1975). The first, third and sixth conditions seem to be fulfilled. Furthermore, some of the hybrids obtained have strong short straw, are lodging resistant and also have good grain quality. But the other conditions have not yet been fully satisfied. However, I am a believer in the future for hybrid wheat and to the question; why then have I abandoned working in this field?--the answer is because of "environmental circumstances" including soil, climate, pathogens and pests as well as all the other factors involved in agricultural research that I have already discussed on other occasions (Sanchez-Monge 1974, 1979).

A favorable circumstance in the utilization of hybrid wheat in the future would be the ease of variety change in case of appearance of a new disease or physiological race. The problem could be solved by changing one of the parents of the hybrid, provided that the collection of male-steriles, restorers and their combinations have been well studied.

The systems male-sterile/restorer permit also their use in breeding programs to obtain easily populations with a high degree of variability. The crosses "male-sterile x restorer" segregate for male-sterility and, mixed with pollinators will produce the variability we are referring to.

Distant hybridization.--Embryo culture, pollen stimulation, *in vitro* pollination and fertilization (Rangaswamy, 1977) and ovary culture after ferilization (Watanabe, 1977) can be used in the hybridization of wheat, not only with species of the genus *Aegilops*, *Secale*, *Haynaldia* and *Agropyron*, but also with *Hordeum* species (Fedak, 1977; Kimber and Salee, 1976; Kruse, 1973; Martin and Chapman, 1977). It is possible that an alloploid with similar uses to that of *triticale* and obtained from *Triticum* x *Hordeum* crosses is just around the corner.

Cell and tissue culture.--The possibility of utilization of cell and tissue cultures in wheat breeding (Gosch-Wackerle et al., 1979; O'Hara et al., 1978; Shimada and Yamada, 1979; Thomas et al., 1979) can be expected due to the results obtained in other plants (Green, 1977; Murashige, 1977; Scowcroft, 1978).

Treating cell or tissue cultures with pathotoxins has permitted selection of resistant variants in cultures derived from susceptible genotypes. Such has been the case with the resistance of tobacco to Pseudomonas tabaci or the resistance of maize to the race T of Helminthosporium maydis (Gengenbach et al., 1977).

Plants with high content of a specific amino acid have been regenerated from cultures by selecting feedback inhibition mutants resistant to toxic levels of amino acid analogs. More difficult would be the selection for characters that are tissue-specific, being limited in their expression to one or few plant tissues and not being found in the cultures.

Haploidy.--The usefulness of haploids in plant breeding, and, in our case, in wheat breeding does not need to be emphasized. Haploids obtained from a segregating population can be used to obtain quickly homozygotes that otherwise would require many generations of selfing. Haploids can also be used in cell, protoplast or tissue cultures to obtain and identify mutants of interest.

Wheat haploids can be obtained from anther cultures. The inclusion of potato extracts in the culture medium seems to favor the yield of embryoids (Research group 301, 1976; Schaeffer et al., 1979).

Several types of alloplasmy increase the frequency of haploid embryos in the seed. Kobayashi and Tsunewaki (1979) have found that a wheat genotype in which the short arm of chromosome 1B has been substituted by an arm of the rye chromosome 1R, induces haploids and twins, mainly of the diplo-haploid type, with relatively high frequencies when, by means of substitution backcrosses, its nucleus is transplanted into an alien cytoplasm such as of some Aegilops species. The possibility of haploid induction by the interaction of an alien cytoplasm and an alien chromosome segment has been so proved.

Techniques for the culture of unfertilized ovaries could be found in wheat similar to those used for rice (Asselin de Beauville, 1980) and barley (San Noeum, 1976). It would be also possible to find for wheat a process similar to the selective chromosome elimination that yields barley haploids from the cross between Hordeum vulgare and H. bulbosum (Jensen, 1977).

Protoplasts.--The possible utilization of protoplasts in plant breeding has been the subject of several reviews (Bajaj, 1977; Dudits et al., 1979; Melchers, 1977).

First it would be necessary to obtain such protoplasts at the haploid or diploid level and to find a technique for the regeneration of whole wheat plants from them. Then several breeding methods could be used: 1) cloning of genotypes that are difficult or impossible to maintain by sexual reproduction; 2) selection, after mutagenic treatment, of lines resistant to various chemicals and toxins; 3) induction and easy detection of recessive mutants in hapoid protoplasts; 4) uptake by wheat protoplasts of whole isolated nuclei, plastids, plasmids, specific DNA segments, nitrogen-

fixing bacteria, or blue-green algae. 5) after the fusion of wheat protoplasts with protoplasts of other species and regeneration of plants of the somatic hybrids the transfer to wheat of genes from remote species by backcrossing or by chromosome grafting after irradiation or treatment with radiomimetic chemicals would also be possible. The first three techniques can be also used with cell or tissue cultures, as mentioned before, but using protoplasts could be more efficient when the technique involves the uptake of compounds by the cell.

Improvement of the photosynthetic efficiency.--Basic research workers seem unanimous in their opinion that plant productivity could be more thoroughly exploited by means of techniques improving the efficiency of processes, such as photosynthesis, that are limiting the productivity.

Photosynthesis contributes to more than 90% of the total plant dry weight and the efficiency in utilization of solar energy by the plants usually does not exceed 1%. The genotypes of wheat that we now use in culture have lower photosynthetic rates than their wild ancestors. It can be stated that the development of methods for increasing solar energy efficiency to 3-5%, optimizing canopy structure, and improving the photosynthetic apparatus would result in wheat yields surpassing 10 tons per hectare.

As there exists variability in dry matter production within wheat genotypes, we also can assume the existance of genetic variability for photosynthetic activity, and therefore, it would be possible to breed for this activity. However, no efficient method of screening is available for a breeding program having this objective.

Nasyrov (1978) has proposed three ways of attack to solve the problem: 1) optimization of the canopy structure as an optical system, 2) improvement of the efficiency of the photosynthetic process itself, 3) partition and rational use of assimilates for the formation of the agronomic yield (harvest index).

According to this author, in the actual wheat genotypes there is an imbalance between the desirable number and size of the economically valuable plant organs and the possibility of providing them adequately with photosynthetic products.

For the improvement of the photosynthetic activity itself Zelitch (1975) has proposed two methods, using tissue cultures in both of them. One of the methods would consist of "selection for superior CO_2 uptake in illuminated plant tissue cultures grown on CO_2 as the carbon source, with the hope that such a phenotype would be expressed in the whole plant". However, some plant tissue cultures do not grow when CO_2 is the only source of carbon. There are some cases in which, even with sucrose as a carbon source, illuminated cultures assimilate CO_2 photosynthetically. The other method proposed by this author is the selection for lower photorespi-

ration in cultures on sucrose, obtaining mutants with lower rates of synthesis of glycolic acid or having a more efficient utilization or regulation of intermediates in the glycolate pathway of carbohydrate synthesis.

Transformation by exogenous DNA.--One of the more fascinating challenges of molecular genetics is the modification of the genetic information of plant cells by transformation with exogenous DNA (Hess, 1977; Lurquin and Kado, 1979). It seems that there is no reason to think that plant cells are more refractary than the prokaryotic or animal cells to the uptake, expression and maintenance of the genetic information contributed by an exogenous DNA. The conditions for the transformation of a cell are: 1) DNA uptake; 2) expression; 3) integration, and 4) replication.

There is direct evidence of the penetration of foreign DNA into plant cells and its becoming covalently linked to the plant DNA, at least into the next plant generation (Brock 1977). Plant protoplasts would be perhaps more easily manipulated for DNA uptake because their DNAase content is lower than in intact cells.

More indirect is the evidence for the full expression, integration and replication of exogenous DNA in plant cells. There are experiments that point towards their occurrence. For instance, treatments of seeds or seedlings of a plant genotype with DNA extracted from another genotype carrying a marker not present in the treated genotype has given rise in some cases to progenies some of which show the marker character and produce plants that breed true for it. Such has been the case of the transformation of a wrinkled seeded maize into smooth seeded, a white flowered Petunia into red flowered and a Capsicum with fasciculated fruit into non-fasciculated (Nawa et al., 1975). Another significant experiment has been the correction of thiamineless character of Arabidopsis thaliana by treating seeds with bacterial DNA extracted from genotypes capable of thiamin synthesis.

In parallel with bacterial genetics mechanisms, a vehicle could be used for the introduction of exogenous DNA into plant cells. This vehicle could be a plasmid or a viral DNA. It has been demonstrated that the cauliflower mosaic virus can be handled as a plasmid with the potential for transfer of genetic information from one plant to another and even from a bacterium to a plant.

A really unorthodox technique of plant transformation is the one proposed by Pandey (1978) and called by this author gametic transformation. The method consists of the pollination of a self-incompatible plant with compatible donor pollen that has been treated with a high dose of irradiation and mixed with incompatible maternal pollen. The donor pollen, even with its chromosomes heavily fragmented, is able to germinate and penetrate into the style discharging its chromatin fragments into the egg. The subsequent development of some diploid parthenogenetic zygotes is possible and some of these zygotes carry in their chromosomes chromatin fragments from the donor pollen. In self-compatible plants such as wheat, the method would yield a lower percentage of transformed

plants because the functioning of the compatible mentor pollen will result in selfings.

Nitrogen fixation.--Nitrogen fixation by way of the natural symbiotic process is of the same order of size, on a world wide basis, as the fixation in the fertilizer production via the Haber process. The artificial transference of the nitrogen fixing capacity to non-leguminous plants by genetic engineering is a dream that, if comes true, will be a good weapon in the fight against hunger. Several facts give us hope that it is really possible.

It has been proved that some strains of rhizobia can fix nitrogen in a non-legume environment, either in direct contact or in the vicinity of non-legume cells. If this lack of inhibition of the bacterial nitrogenase activity holds true for intact plants, the development of associations between nitrogen-fixing rhizobia and non-leguminous plants would be possible. It has been possible to transfer a part of a nif operon from Klebsiella to a small amplifiable plasmid. Therefore, it should be possible to construct plasmids carrying nif genes.

There have been found cases of association between genotypes of Gramineae belonging to the genus Paspalum, Zea, Saccharum and Oryza and nitrogen-fixing microorganisms that were identified in the beginning as Spirillum but now have been separated into another genus, Azospirillum (Dobereiner, 1979). Therefore, there seems to exist the possibility of constructing or perfecting, by simultaneous genetic manipulation of the plant and microorganism, a system in wheat parallel to that of the legume-rhizobium system.

Perhaps it also would be possible to apply to wheat in the future a technique similar to that proposed for other plants (Dixon, 1978; Casedesus y Olivares, 1978) using Agrobacterium tumefaciens strains carrying the Ti plasmid that induces tumor formation in some plants when a fragment of such plasmid is inserted in the plant genome and replicates. For the success of this method it would be necessary to insert nif genes into the Ti plasmid and manipulate the insertion in order to inactivate the tumor-inducing ability. It also would be necessary that the plant machinery for transcription and translation could recognize the prokaryotic promoters, initiators and terminators.

In some of the more or less unorthodox methods that have been mentioned here there are surely too many ifs. But there is a sure way of using even the less orthodox methods for obtaining financial support for the orthodox ones. When you are requesting funds for your research, if you propose simply a classical orthodox wheat breeding propram you will surely have less probability of obtaining the funds than if you describe a very unorthodox program. I will finish my talk by giving you this advice after more than 30 years of fighting against bureaucracy. Prepare proposals containing a great deal of unorthodox methods and use the bigger part of the funds obtained for financing your orthodox programs.

References

Asselin de Beauville, M. 1980. Obtention d'haploids in vitro a partir d'ovaries fecondes de riz Oryza sativa L. C. R. Acad. Sci. Paris. 290:489-492.

Auriau, Ph., P. Pluchard et B. Masseret. 1975. Recherches sur la viguer hybride chez le ble. I. Ann. Amelior. Plantes 25:177-199.

Bajaj, Y. P. S. 1977. Protoplast isolation, culture and somatic hybridization. In Plant cell, tissue and organ culture. J. Reinert and Y. P. S. Bajaj(Eds):467-496.

Brock, R. D. 1977. Genetic engineering and plant improvement. J. Aust. Inst. Agric. Sci. 43:14-21.

Carlson, P. S and T. B. Rice. 1977. Genetic engineering and plant improveme t. HortScience 12:135-137.

Casadesus, J. y J. Olivares. 1978. Genetica de Rhizobium y de la fijacion del nitrogeno. An. Edaf. Agrobiol. 37:916-948.

Child, J. J. 1976. New developments in nitrogen fixation research. BioScience 26:614-617

Davies, D. R. 1977. Creation of new models for crop plants and their use in plant breeding. Appl. Biol. 2:87-127.

Dixon, R. 1978. Genetic engineering in the fields. New Scient. 1978:684-686.

Dobereiner, J. 1979. Fixacao de nitrogenio em gramineas tropicais. Intersciencia 4:200-205.

Dudits, D., G. Hadlaczky, G. Y. Bajszar, Cs. Koncz, G. Lazar and G. Horvath. 1979. Plant regeneration from intergeneric cell hybrids. Plant Sci. Letters. 15:101-112.

Fedak, G. 1977. Increased homoeologous chromosome pairing in Hordeum vulgare x Triticum aestivum hybrids. Nature 266:529-530.

Gengenbach, B. G., C. E. Green and C. M. Donovan. 1977. Inheritance of selected pathotoxin resistance in maize plants regenerated from cell cultures. Proc. Natl. Acad. Sci. USA. 74:5113-5117.

Gosch-Wackerle, G., L. Avivi and E. Galun. 1979. Induction, culture and differentiation of callus from immature rachises, seeds and embryos of Triticum. Z. Pflanzenphysiol. 91:267-278.

Green, C. E. 1977. Prospects of crop improvement in the field of cell culture. HortScience 12:131-134.

Hess, D. 1977. Cell modification by DNA uptake. In Plant cell, tissue and organ culture, J. Reinert and Y. P. S. Bajaj(Eds):506-534.

Jensen, C. J. 1977. Monoploid production by chromosome elimination. In Plant cell, tissue and organ culture, J. Reinert and Y. P. S. Bajaj(Eds):299-340.

Kimber, G. and P. J. Sallee. 1976. A hybrid between Triticum timopheevi and Hordeum bogdanii. Cer. Res. Comm. 4:33-37.

Kobayashi, M. and K. Tsunewaki. 1979. On the genetic mechanism of haploid induction in the cytoplasm substitution lines of common wheat. Wheat Inf. Serv. 47-48:36-40.

Kruse, A. 1973. Hordeum x Triticum hybrids. Hereditas 73:157-161.

Lurquin, P. F. and C. I. Kao. 1979. Recent advances in the insertion of DNA into higher plant cells. Plant, Cell and Environ. 2:199-203.

Martin, A. and V. Chapman. 1977. A hybrid between Hordeum chilense and Triticum aestivum. Cer. Res. Comm. 5:365-368.

Melchers, G. 1977. The combination of somatic and conventional genetics in plant breeding. Plant Res. and Develop. 5:86-110.

Mukade, K. 1978. Chromosome engineering and acceleration of generation advancement in breeding rust resistance wheat. Trop. Agric. Res. Series 11:135-144.

Murashige. T. 1977. Current status of plant cell and organ cultures. HortScience 12:127-130.

Nasyrov, Y. S. 1978. Genetic control of photosynthesis and improving of crop productivity. Ann. Rev. Plant Physiol. 29:215-237.

Nawa, S., M. A. Yamada and Y. Ohta. 1975. Hereditary changes in Capsicum annuum L. III. Induced by DNA treatment. Jap. J. Genet. 50:341-344.

O'Hara, J. F. and H. E. Street. 1978. Wheat callus culture: the initiation, growth and organogenesis of callus derived from various explant sources. Ann. Biol. 42:1029-1038.

Ozbun, J. L. 1978. Photosynthetic efficiency and crop production. HortScience 13:678-679.

Pandey, K. K. 1978. Novel techniques of gene transfer and plant improvement: an appraisal of transformation in eukaryotes. New Phytol. 81:685-704.

Rangaswamy, N. S. 1977. Applications of in vitro pollination and in vitro fertilization. In Plant cell, tissue and organ culture. J. Reinert and Y. P. S. Bajaj(Eds):412-425.

Research Group 301. 1976. A sharp increase of the frequency of pollen-plant-induction in wheat with potato medium. Acta Genet. Sinica 3:25-31.

San Noeum, L. H. 1976. Haploides d'Hordeum vulgare L. par culture in vitro d'ovaries non fecondes. Ann. Amelior. Plantes 26:751-754.

Sanchez-Monge, E. 1974. Fitogenetica.

Sanchez-Monge, E. 1979. Cooperacion Internacional en la Mejora de Plantas. XV Jornadas Luso-Espanolas de Genetica. Lisboa.

Schaeffer, G. W., P. S. Baenziger and J. Worley. 1979. Haploid plant development from anthers and in vitro culture of wheat. Crop Sci. 19:697-702.

Scowcroft, W. R. 1978. Aspects of plant cell culture and their role in plant improvement. Proc. Symp. Plant Tissue Culture Peking: 181-197.

Shimada, T. and Y. Yamada. 1979. Wheat plants regenerated from embryo cell cultures. Jap. J. Genet. 54:379-385.

Sutka, J. 1979. Some aspects of use of aneuploidy in wheat breeding. Acta Agron. Acad. Sci. Hungaricae. 28:401-422.

Thomas, E., P. J. King and I. Potrykus. 1979. Improvement of crop plants via single cells in vitro-- an assessment. Z. Pflanzenzucht. 82:1-30.

Watanabe, K. 1977. Successful ovary culture and production of F_1 hybrids and androgenic haploids in Japanese Chrysanthemum species. J. Hered. 68:317-320.

Zelitch, I. 1975. Improving the efficiency of photosynthesis. In Food: politics, economics, nutrition and research, P. H. Abelson(Ed):171-177.

Zobel, R. W. and D. H. Wallace. 1978. Potential for nitrogen fixation in vegetables. HortScience 13:679-682.

REFLECTIONS ON THE THEORETICAL BASIS FOR PRODUCING MULTIPLE CROSSES

Laszlo Balla
Hungary

The wheat breeding methods currently in use have been developed over the past few decades and have resulted in the production of numerous new varieties in all parts of the world. Such outstanding varieties as the Italian Mentana, San Pastore, Libellula, etc., the Soviet Bezostaya 1, Mironovskaya 808, Odessa 51, etc., the American Scout, Centurk, Gaines, Arthur, etc., the West European Cappelle Desprez, Heine, Jubilar, etc., and the Mexican Lerma Rojo 64, Siete Cerros, Jupateco, etc., have been developed to name just the best-known.

At present, it seems that the possibilities latent in these methods have been exhausted. If breeders wish to achieve resounding successes comparable to those listed above, either a new philosophy or a re-evaluation and development of the present concepts will be necessary. A repetition of the old methods may lead to a refinement of the results already achieved, but is hardly likely to lead to a breakthrough.

The most important breeding philosophies were developed by Sedlmayr (1926), Heuser (1928), Vavilov (1935), Akerman and Mac Key (1948), Frankel (1947, 1950), Lukyanenko (1949, 1965), Rudorf (1956), Borlaug (1958), Lupton (1966), Remeslo (1967), Borojevic (1975), Jensen (1975), and others. However, these are all yield-centered concepts.

Today a triple requirement must be met by new varieties in terms of quantity, quality, and yield stability.

The Hungarian varieties produced in recent years already approach these criteria, so several of them are already grown on large areas. At present, Martonvasari 4 has the second largest growing area of any variety in Hungary. Even better results are expected from the later varieties Mv 5, Mv 6, Mv 7, Mv 8, and Mv 9, which will be registered shortly. These varieties are now spreading as they combine high yielding ability with good winterhardiness, high quality, and short stems. But development cannot stagnate. In the future, even better varieties will be required.

The aim of Hungarian breeders today is to produce a good quality wheat with yielding ability of around 100 q/ha which is suitable for combine harvesting (70-80 cm tall), winterhardy, and resistant to diseases (powdery mildew, stem and leaf rust). In some years resistance to root rot diseases and adaptability (to drought, heat) are also important. Thus, improvements must be made in yielding ability and in resistance to lodging and diseases (powdery mildew, stem and leaf rust, root rot) while quality,

Agricultural Research Institute of the Hungarian Academy of Sciences, Martonvasar

winterhardiness, and drought resistance must be maintained at the level achieved at present in the best varieties.

Initial Stock

The success of breeding depends in great measure on the choice of initial stock.

The crossing partners may be:
- foreign varieties
- domestic varieties
- local varieties and sources
- lines produced by the breeder himself.

The old principle whereby one of the partners in every cross must be a well-proven domestic variety is no longer strictly adhered to, but breeders still endeavor to choose crossing partners with ecotypes which can be grown in Hungary. Unfortunately, the degree of relationship between varieties is increasing. Bezostaya 1 often appears in the genealogy of the new varieties produced in Central and Eastern Europe, thus increasing the genetic vulnerability of the varieties. Despite the difficulties involved, it is essential to include foreign genotypes in the crosses. The American variety, Arthur, for example, is an excellent source of resistance, but it is difficult to eliminate its undesirable traits (long-thin stem, poor quality, long vegetation period).

Theoretical Basis for Compiling a Crossing Program

When compiling the crossing program the aim is to produce a hybrid population in which all the desired characters are found. Winterhardiness and quality must be regarded as basics; transgression can be expected in the development of yield components; while resistance to powdery mildew, stem and leaf rust, short stature, and earliness must be "built in". The first phase of the process is analysis, consisting of a study of the characters and origin of the crossing partners. This is followed by the second phase, synthesis, in which a hybrid population is synthesised to include the important agronomic characters which the breeder aims to unite in one variety. The production of a synthetic hybrid population is designed to give the greatest possible variability in the characters. If this is successful, it is a relatively easy matter to find the desired ideotype when selecting.

In order to increase variability, multiple or complex hybrid combinations are created. The factors which make up the theoretical basis for the selection of crossing partners are genetic diversity, which ensures good biological combining ability and vitality; a contrast between the yield components, which is the basis of transgression; and the presence of other agronomic characters (earliness,

resistance to powdery mildew, stem and leaf rust) in an opposite or more highly developed form than in the original which makes it possible for characters to combine and for new, valuable genotypes to appear.

The Formation of Hybrid Combinations

Less complicated breeding tasks can be solved by simple hybridization, topcrossing, or backcrossing; but the more complicated problems which face the breeder today require multiple crosses or different variants of the convergent method (Mac Key, 1962; Borojevic and Potocanac, 1966). In the case of multiple crosses, however, the question arises of how to synthesize a hybrid population in which the characters combine in the manner most favorable to the breeder.

A knowledge of the inheritance patterns of the character, the heritability, the genetic relationships, and the dominance conditions gives useful information towards selecting the crossing method. For example, whether reistance is mono- or polygenic, whether short stature is a dominant or recessive trait, how these are combined with other favorable or unfavorable traits, etc. Gene accumulation seems to be most successful if there are a large number of easily transferable monogenic traits.

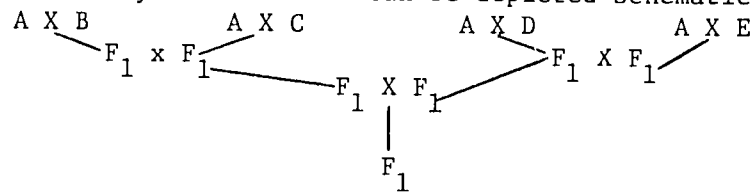
One method of combining characters in which are to be found in several varieties, is sequential crossing which can be depicted schematically as follows: {[(A X B) X C] X D} X E.

In this method the characters of five parents can be united. It takes four years to produce this combination in the field. It has the disadvantage of taking up a considerable length of time and of twice necessitating the crossing of a segregating population. When using this method the following rule must be observed. First, varieties with simply inherited, easily recognizable traits (e.g. earliness, resistance) are crossed (A X B). The top cross (C) is also made with an easily recognizable (e.g. dwarf) variety, while the high quality, winterhardy (D) and high yielding (E) varieties are left to the last since the germplasms of the last varieties make up a high percentage (25% for D and 50% for E) of the hybrid, which means that the characters of these varieties are strongly expressed. At the same time it is an easy matter to select for the simply inherited, easily recognizable traits of the parents used in the first crosses.

When crossing a segregating population the later development of the characters can be influenced by which plants are selected. If, for example, short early, resistant plants are chosen for crossing, the probability that these characters will appear in later generations is increased. In some cases, it is advisable to use two parents to develop a certain character as this may be the only way to achieve desired results. Earliness and short

stature, for example, easily disappear if they are not sufficiently well-founded genically. Many short-stemmed varieties have no gene for dwarfness so when they are crossed they behave like tall varieties. These varieties are not true semidwarfs, but "restricted" tall varieties, and they will not lead to a semidwarf hybrid population.

The second way in which synthetic hybrid populations can be produced is with the convergent crossing method, several variants of which are known. One of these which has been used in recent years at Martonvasar to produce numerous hybrid populations, will be described in detail. The method was suggested by Akerman and Mac Key (1948), but there seems to be no record of it having been used systematically. The method can be depicted schematically as follows:



Three crossing programs and five varieties are required to produce the final hybrid.

The method includes one basic variety and four pollinators, from which some particular character is to be transferred from each. By using the basic variety on a number of occasions, the characters of the hybrid population are "shifted" in a predetermined direction. The proportion of the germplasms from the individual varieties in the population will be 50:12.5:12.5:12.5:12.5 %, i.e., the basic variety dominates. In order to produce this combination the following rule must be observed.

The basic variety should be a high yielding, good quality, winterhardy wheat, since these characters cannot be distinguished when selecting the F_2 population. The pollinating varieties should differ from each other ecologically and/or genetically, and, if possible, their yield components should be contrasting, i.e., they should differ from those of the basic variety. In addition, these varieties are the sources of earliness, short stature, and disease resistance. Certain characters must be introduced with several pollinators so that the probability of finding them in the hybrid population will be greater. In order to achieve short stature, for instance, one dominant and one recessive source of dwarfness are usually crossed. The situation is facilitated by the fact that many of our lines already are semidwarf and resistant, so the two characters can be introduced simultaneously. This method, too, allows the characters of the population to be influenced, if plants which satisfy the breeding aims are designated for crossing in the segregating F_1 population in the third program.

The synthetic hybrid population thus has a foundation of high yielding ability, quality, and winterhardiness, while characters

such as short stature, earliness, and resistance to powdery mildew and stem and leaf rust, which are easily recognizable in the F_2, are introduced at later stages. The development of yielding ability is based on transgressive recombinations which are promoted by the crossing of varieties with contrasting yield components. Genetic differences also make a contribution. Earliness, short stature and resistance are based on gene linkage and gene accumulation, i.e., on the appearance of new genotypes, which is promoted if the characters have high heritability (h^2 values). In addition, varieties with a broad genetic background can be expected to possess good adaptability which is necessary if they are to spread.

The long period required to produce multiple crosses discourages many breeders from using the method. In many institutes, including Martonvasar, phytotrons now operate, making it possible to raise several generations a year (Balla, 1980). In the phytotron the time required even for the longest crossing processes can be reduced to half, thus making the method much more acceptable.

References

Akerman, A. and J. Mac Key. 1948. The breeding of self-fertilized plants by crossing, 46-71. "Svalof, 1886-1946". Ed. by A. Akerman, Carl Bloms Boktryckeri. A. B. Lund.

Balla, L. 1980. Gyorsitott buzanemesitesi eljaras fitotronban (Accelerated wheat breeding process in the phytotron). Novenytermeles 3.

Borlaug, N. E. 1958. The use of multilineal or composite varieties to control airborne epdemic diseases of self-pollinated crop plants. Proc. First Int. Wheat Genet. Symp. Winnipeg. p. 12-26.

Borojevic, S. 1975. Ideotypes for high productivity, performance stability and adaptation. Proc. Second Int. Winter Wheat Conf., Zagreb, Yugoslavia. p. 46-60.

Borojevic, S. and J. Potocanac. 1966. The development of the Yugoslav program for creating high-yielding wheat varieties. Savremena polj. XIV(11-12):7-35. Novi Sad.

Frankel, O. H. 1947. The theory of plant breeding for yield. Heredity 1:109-120.

Frankel, O. H. 1950. The development and maintenance of superior genetic stocks. Heredity 4:89-102.

Heuser, W. 1928. Die Ertragsanalyse von Getreide-zuchtungen, Pflanzenbau. 4:353.

Jensen, N. F. 1975. Breeding strategies for winter wheat improvement. Proc. Second Int. Winter Wheat Conf., Zagreb, Yugoslavia. p. 31-46.

Lukyanenko, P. P. 1949. Selektsia ozimoi pshenitsi na Kubani. Nauchnii otchet K.G.S.S. za 1937-1948. Krasnodar 1:11-112.

Lukyanenko, P. P. 1965. The development of high yielding winter wheat varieties with high quality grain. Acta Agriculturae Scandinavica, Stockholm, Suppl. 16:321-330.

Lupton, F. G. H. 1966. The use of physiological characters in breeding for yield in wheat. Qual. Plant. Nat. Veg., Den Haag 13:375-376.

Mac Key, J. 1962. The 75 year development of Swedish plant breeding. Hadowla Roslin, Aklimat. i Nasie 6:4-5.

Remeslo, V. N. 1967. Ot Ukrainki k Mironovskoi-Jubileinoi. 50. Selektsia i Semenovodstvo 1:13-16.

Rudorf, W. 1956. Neue Grundlagen und Methoden zur Zuchtung auf Leistung. Z. Pflanzenzuchtung, Berlin-Hamburg. 35:441-460.

Sedlmayr, K. 1926. Die Bedeutung der Bestandesdichte als Ertragskomponente des Weizens. Fortschr. d. Landw. 2:377-381.

Vavilov, N. I. 1935. Nauchnie osnovi selektsii pshenitsi. Selkhozgiz, Moscow-Leningrad. 246.

A COORDINATED APPROACH TO CROP IMPROVEMENT: INDIA'S EXPERIENCE WITH WHEAT.

M. V. Rao
India

Abstract

India has achieved reasonably good success, although potentialities exist for greater achievements, in raising its food production in recent years. From a chronically deficit state a few decades ago, it was able to build sizeable buffer stocks of food grains which in 1979 rose to 20.5 million tons. Wheat is one of the main constituents of this buffer stock whose productivity, after stagnating for nearly half a century, rose steeply in the last twelve years bringing a revolutionary change in the country's production front. India's experience in raising its food grain production from 50.8 million tons in 1950-51 to 131.4 million tons in 1979 with plans to raise it to 182 million tons by the turn of this century will be of interest to others, particularly to those countries whose food requirements are increasing with their increase in population.

Increased agricultural production is possible when a package of economically viable technology supported by appropriate package of services and public policies is available. Wheat in India received this support from all directions with the result that its production rose from 11.4 million tons in 1967 to 34.9 million tons in 1979, a three-fold increase in a short period of 12 years. Its productivity rose in the same period from 890 kgs to 1574 kgs/H. One of the inputs that was responsible for bringing this change in the form of high yielding varieties and better production and production technology came from the large number of scientists of various disciplines working in or collaborating with the All-India Coordinated Wheat Improvement Project of the Indian Council of Agricultural Research. Their identification of semidwarf wheats that are amenable to exploitation by high levels of chemical fertilizers and irrigation doses sparked the green revolution. New varieties, further refinements in production and production technology brought a considerable amount of stability into India's wheat production efforts.

Introduction

India's recent success in wheat production is a classical example of fruitful interaction between international collaboration and harmonious blending of the local talent and resources. A long search by the Indian scientists for genotypes that could be exploited through intensive agricultural practices bore fruit when

Wheat Project Directorate, IARI, New Delhi

the semidwarf wheats, carrying the Norin-10 dwarfing genes of Japanese wheats and produced by the Rockefeller/CIMMYT scientists in Mexico, reached India in 1961-62 through the International Spring Wheat Rust Nurseries organized by the United States Department of Agriculture. Like the hexaploid wheats which resulted from the harmonious blending of three different genomes, the scientists in India belonging to different disciplines, different states, and centers worked as a team to achieve the goal of self sufficiency in wheat production. The country had the good fortune of the needed infrastructure for raising production: dedicated scientists, progressive and sound governmental policies, capacity to produce inputs like fertilizers, plant protection chemicals, seed, water resources and, finally, receptive farmers to exploit the new varieties and technology. To these favorable factors one more needs to be added in the form of the All-India Coordinated Wheat Improvement Project which, through its network of stations and multidisciplinary teams of scientists, started the spark and gave the necessary scientific and demonstrational support to the total wheat production efforts of the country.

Wheat production in the first crop season after partition of the country (1947-48) stood at 5.6 million tons with a very low productivity of 671 kgs/H. India had to rely heavily on imports, particularly on the PL-480 funds, to meet its growing internal demands. Efforts were made, in the absence of adequate quantities of chemical fertilizers and water, to increase the wheat area and raise production and yield/ha. By 1964-65 the area went up from 8.4 to 13.5 million hectares, production to 12.3 million tons, and productivity to 913 kgs/ha. However, during the same period the population rose from about 350 to 480 million. To meet the per capita requirement of this second most important food cereal of the country, there was little option other than to import. In the absence of lodging resistant, fertilizer-responsive varieties, even the Intensive Agricultural District Program (IADP) initiated in 1961-62 did not produce any marked improvement in spite of a package of improved management practices based on greater use of water and fertilizer. Although it was fully realized that the right wheat genotype holds the key for exploiting intensive agricultural practices, such genotypes were not available. Some Italian semidwarfs like Fortuno, Faltchello, and Funo were spotted and used to transfer their short and stiff straw into Indian wheats but not much progress could be made because of their high degree of susceptibility to rusts. Mutations were tried but with limited commercial exploitation. It was at this stage that the semidwarf wheats like Sonora 64, Lerma Rojo 64 etc. developed by Dr. Norman E. Borlaug and his associates in Mexico came to India through the International Spring Wheat Rust Nursery of the USDA. This is the type of genotype that the Indian wheat scientists were looking for and the potential offered by these wheats was fully exploited immediately (for greater details refer to "Five years of research on dwarf wheats" and "Wheat research in India 1966-1976", ICAR, New Delhi). The original red-grained types had to be replaced by amber grain types to meet consumer preference. More and more wheats were identified and developed

subsequently which, coupled with appropriate production and protection technology, brought the steep rise in production in later years.

Achievements

Between 1967-68 (the year of initial impact of the wheat revolution) and 1978-79 India harvested additional wheat grain amounting to 153.5 million tons worth 143.4 billion rupees (eight Indian rupees are about equivalent to 1 U.S. $). The highest production that was ever obtained with the tall conventional wheats was in 1964-65 which is taken as the base year (Table 1).

Table 1. Monetary benefits of wheat revolution in India.

Year	Production (in million tons)	Additional production over base year (in million tons)	Procurement price/ton (in rupees)	Cost of additional grain (in mullion rupees)
1964-65 (base year)	12.3	--	--	--
1967-68	16.5	4.2	750	3150
1968-69	18.5	6.2	750	4650
1969-70	20.1	7.8	750	5850
1970-71	23.8	11.5	750	8625
1971-72	26.4	14.1	750	10575
1972-73	24.7	12.4	750	9300
1973-74	22.8	10.5	750	7875
1974-75	24.2	11.9	1050	12495
1975-76	28.8	16.5	1050	17325
1976-77	29.1	16.8	1050	17640
1977-78	31.3	19.0	1100	20900
1978-79	34.9	22.4	1120	25099
	Total grain:	153.5	Total value:	143484 (million rupees)
			or	143.4 (billion rupees)

The figure of Rs 143.4 billion is based on local prevailing prices in India at different periods of time. However, it should be realized that if India had to import this quantity of wheat the figure would have to be substantially revised upwards and would include shipment and local freight charges.

The impact of new wheat varieties and the new technology is reflected in the rise of area under this crop, production, and productivity per unit area (Table 2).

Table 2. Recent trends in area, production, and productivity/ha of wheat in India.

Year	Area (mill. ha)	Production (mill. tons)	Productivity/ ha (kgs)	Remarks
1947-48	8.4	5.6	671	First crop year after Independence.
1961-62	13.5	12.0	890	Year of All-India approach.
1964-65	13.5	12.3	913	Highest yield with tall conventional wheats.
1967-68	15.0	16.5	1103	First year of impact of semi-dwarf H.Y.V.
1968-69	16.0	18.5	1169	
1969-70	16.6	20.1	1208	
1970-71	18.2	23.8	1307	
1971-72	19.1	26.4	1380	
1972-73	19.4	24.7	1271	
1973-74	18.5	21.8	1172	
1974-75	18.1	24.2	1338	
1975-76	20.4	28.8	1410	
1976-77	20.9	29.0	1480	
1977-78	21.4	31.7	1477	
1978-79	22.2	34.9	1574	

Source: Directorate of Economics & Statistics, Ministry of Agriculture & Irrigation, Government of India.

The farmers, by and large, found by experience that cultivation of wheat is more remunerative than many other crops which they are growing. In every state there was near doubling of the wheat area (Tables 3 and 4). Being poor, the average Indian farmer welcomes improved varieties which do not involve additional investment to improve his yields, rather than depend on chemicals etc. which involves heavy recurrent expenditures year after year.

As will be seen from Table 3 wheat has become important even in non-traditional areas like West Bengal and Maharashtra. In fact, India still has a considerable untapped reservoir of areas in the eastern and southeastern parts of the country which have not been exploited so far.

Table 3. Impact of productivity of wheat on acreage and productivity in some selected states.

State	Year	Area (mill. ha)	Production (mill. tons)	Yield/ha (kgs)
Uttar Pradesh	1965-66	4.1	3.7	912
	1978-79	7.2	11.2	1546
Madhya Pradesh	1965-66	2.4	1.3	553
	1978-79	3.5	3.3	925
Punjab	1965-66	1.5	1.9	1237
	1978-79	2.7	7.4	2715
Haryana	1965-66	0.7	0.9	1282
	1978-79	1.5	3.4	2300
West Bengal	1965-66	0.04	0.03	825
	1978-79	0.5	1.0	1916
Maharashtra	1965-66	0.9	0.3	336
	1978-79	1.2	0.9	802

Table 4. Effect of new wheats and technology on productivity in some selected districts.

State	District	Year	Area (mill. ha)	Production (mill. tons)	Yield/ha (kgs)
Uttar Pradesh	Aligarh	1965-66	0.11	0.16	1390
		1976-77	0.2	0.4	1845
	Kanpur	1965-66	0.10	0.1	964
		1976-77	0.14	0.2	1754
	Varanasi	1965-66	0.04	0.03	795
		1976-77	0.09	0.1	1217
Madhya Pradesh	Gwalior	1965-66	0.07	0.05	726
		1976-77	0.08	0.09	1091
Punjab	Ludhiana	1965-66	0.15	0.28	1875
		1976-77	0.25	0.8	3159
	Jullundur	1965-66	0.13	0.16	1209
		1976-77	0.21	0.5	2423
Haryana	Karnal	1965-66	0.21	0.27	1286
		1976-77	0.2	0.4	2323
	Hissar	1965-66	0.12	0.13	1084
		1976-77	0.14	0.3	1979

One of the impacts of the wheat revolution is its increasing contribution to the total food grain production of the country and also in the building up of buffer stocks of food grains (Table 5). The contribution of wheat to the total food basket in 1966, before the impact of the wheat revolution, was 13.7 percent and by 1979 its contribution almost doubled to 26.6 percent. Similarly, the contribution of wheat to the total grain reserves rose from 0.2 to 8.0 million tons in the same period. Even in the worst drought year of this century, 1979-80, the contribution of wheat to the buffer stocks is expected to be 8.0 million tons. This shows the stability of the present wheat situation.

Table 5. Contribution of wheat to total food grain production and buffer stocks.

Year	Total food grain production	Wheat production	Percentage contribution of wheat to total food grains production	Buffer stock of total food-grains	Contribution of wheat to buffer stock
	(mill. tons)	(mill. tons)		(mill. tons)	(mill. tons)
1966	74.2	10.3	13.7	0.6	0.2
1969	94.9	18.6	19.8	3.4	2.4
1972	105.2	26.4	25.1	6.1	5.0
1975	99.8	24.1	24.1	3.0	4.1
1978	125.9	31.7	25.2	13.8	5.5
1979	131.4	34.9	26.6	20.5	8.0

The role of the coordinated approach in India's agriculture

The present All-India Coordinated Research approach is a sequence of several historical developments over a period of time (Randhawa, 1979). Agriculture in India is a state subject. Work related to development, research, teaching, and extension is looked after by the Departments of Agriculture and Agricultural Universities in each state. The Indian Council of Agricultural Research (ICAR) which came into existence in 1928 has been the organization which coordinated research in different disciplines in the past through its various Committees and Commodity Committees (oilseeds, cotton, sugar cane, lac, etc.). This approach subsequently changed to the Project for Intensification of Regional Research on Cotton, Oilseeds and Millets (PIRRCOM) to facilitate intensified regional research on specific crops.

Based on the experience of the coordination over years the ICAR initiated a number of All-India Coordinated Research Projects in 1965-66 that covered crops, animals, soils, agronomy, engineering, fish, etc. To quote the 1965-66 annual report of the ICAR "A cardinal feature of these coordinated research projects is that they will be operated on a country-wide basis under the direct supervision and technical guidance of the ICAR. Each project will be headed by a full-time project coordinator and a number of zonal coordinators and technical project leaders. In this way the Central Research Institutes, as well as the Agricultural Universities and Departments of Agriculture in states where Agricultural Universities do not exist, will work as a team in the solution of the important agricultural research problems. This is a significant departure from the practice in the past when research effort was made in a fragmentary isolated manner. The All-India Coordinated Research Projects provide a major and an important forum and vehicle for placing agricultural research in the country on a sound basis". The objectives of these projects are to undertake problem-oriented applied research and testing of knowledge or technology under different broad agro-climatic conditions. It is also envisaged that the problems studied should be of national importance and the aim should be to develop recommendations in the shortest possible time to improve production or solve the problems for which the research effort was mounted.

It is acknowledged that the benefits that have accrued from the All-India Coordinated Research Projects have resulted in stabilizing the economy of the agricultural system as a whole and production and productivity in particular. The reasons for the success of the projects are:

1) Cooperation between scientists working in the states and the scientists of the Central institutions;

2) appointment of a full-time coordinator who inculcates a feeling of oneness of the whole program and works for the good of all regions of the country;

3) availability of germplasm and experimental materials, national and international, to the different scientists in the shortest possible time;

4) multidisciplinary and soil- and climate-based approach in solving problems;

5) mutual visits of scientists of each zone to different centers to understand the problems of each other;

6) open and frank discussions in zonal and annual All-India workshops;

7) free exchange of material between scientists and stations which was not possible earlier;

8) facility for testing material developed at one station/zone across the boundaries of that station/zone;

9) screening of material generated at each station through multi-location tests against diseases, pests, and also for broad agronomical suitability;

10) advancement of generations, screening against diseases, and initial multiplication of promising strains in the off-season nurseries;

11) ability to assist weaker stations and also extend wheat cultivation to areas where there is limited infrastructure;

12) organize seed multiplication of varieties which are of zonal/national importance;

13) ability and resilience to meet challenges on short notice; and finally,

14) involvement of developmental agencies and research workers in production and other efforts.

The greatest advantage of the All-India approach is the ability or resilience to face a challenge as a team at the national level. For example, when weeds like Phalaris minor and wild oats became a serious national problem our scientists could move fast to identify chemicals or technology to control them. Similarly, when drought like the unprecedented one of 1979-80 came, the wheat scientists gave suitable technology and guidelines that minimized losses, which otherwise would have led to serious crop damage. Even in this difficult year, it is estimated that 2.0 million tons of wheat grain will be added to our buffer stocks.

One of the crucial factors that encouraged wheat production is the progressive policies of the Government in terms of insuring a minimum price for the produce, subsidies on inputs, and reallocation of power, when needed, for agricultural purposes rather than for industries etc.

All-India Coordinated Wheat Improvement Project (AICWIP)

The ICAR initiated about 54 All-India Coordinated Research Projects (some were terminated later) and wheat is one of them. Some of the major projects like rice, wheat, oilseeds, pulses, dry-land agriculture, and soil survey have been elevated to the level of Project Directorates. The AICWIP started functioning on an ad-hoc basis in 1962 and on a regular basis since 1967 with the appointment of a full-time coordinator. The Rockefeller Foundation in India gave considerable support in the initial stages of the project. The coordinator or project director is assisted by principal investigators in each of the disciplines such as pathology, agronomy, quality, entomology, nematology, breeding and physiology.

The principal investigators knit the program of all centers pertaining to their respective disciplines. The wheat project is responsible for the improvement of aestivum, durum and dicoccum wheats and also triticale.

The country is divided into 9 zones based on soil and climatic conditions. In each zone there are wheat research centers supported either by the funds of the wheat project or the State Governments (Table 6).

Whatever the source of the funds, the scientists working at all of these centers actively collaborate with the AICWIP and join in planning and decision making as equal partners. The organization of different series of trials is done by a zonal coordinator in each zone. He also organizes the meeting of the wheat workers of the zone during the crop season so that they may move as a team in visiting field experiments at selected centers.

All the wheat scientists specializing in different disciplines, senior officials of the departments of agriculture of Central and State Governments, the senior officials of the ICAR, officials of the seed-producing and certification agencies, a selected number of progressive farmers, directors of research in the Agricultural Universities meet once a year in the All-India Wheat Research Workers' Workshops to review the work of each discipline and plan the program for the following year. Recommendations on varieties, chemicals, practices or strategies for increasing production or control of particular pests, diseases, nematodes, weeds, imports of chemicals, etc. are made in these workshops for implementation. The workshops serve not only as vehicles for exchange of information, reviewing and planning of work of all disciplines, but also as a meeting point of scientists, policy makers, developmental agencies, and program executors. In addition to these workshops, special meetings are arranged to focus attention on basic aspects of wheat improvement, control of serious diseases and weeds, etc., or new problems that may arise.

Types of experimentals/trials carried out in AICWIP

In a nutshell, the types of experiments carried out by AICWIP in each of the 9 zones of the country on wheat and triticale are as follows:

a) Breeding: Trials with strains under different crop production conditions. These conditions include low fertility rainfed, high fertility irrigated (separate trials under timely sown and late sown). Each year 500-600 trials involving more than 1000 strains are conducted. National trials, screening of international materials, National Genetic Stock Nursery, Nursery of Thermo-insensitive Strains, and organization of off-season nurseries and tests are some of the other activities.

Table 6. Area and centers of research in the 9 wheat zones.**

Zone	State/part of State	Centers of wheat research	Approximate area of the zone (1000 ha)
Northern Hills	Hills of U.P., H.P. & J.K.	Almora*, Bhowali*, Simla, Bajuara, Palampur*, Srinagar*, Dhaulakuan, Lahaul***	533
Northern Plains	Punjab, Jammu, Eastern Haryana & Rajasthan, Western U.P., Delhi, & Northern M.P.	Ludhiana*, Gurdaspur, R.S. Pura, Karnal, Pantnagar*, Delhi*, Sriganganagar	7394
North Western	Western Rajasthan & Haryana, Northern Gujarat	Durgapura*, Hissar*, Vijapur*	1881
North Eastern	Eastern U.P., Northern Bihar	Kanpur*, Varanasi*, Faizabad, Pusa*, Patna, Sabour*	4067
Far Eastern	West Bengal, Southern Bihar, Assam, Manipur, Meghalaya, Nagaland, Mizoram, Tripura, Arunachal Pradesh	Kalyani*, Malda*, Ranchi, Shillongoni*, Imphal	1281
Central	Western M.P., Southern Gujarat, Southeastern Rajasthan	Powarkheda*, Sagar*, Indore*, Kota*, Udaipur*, Junagadh*	3836
South Eastern	Orissa, Eastern M.P., Coastal Andhra, North-eastern Maharashtra	Bhubaneswar*	293
Peninsular	Maharashtra, Karnataka, Western Andhra Pradesh and plains of Tamilnadu	Niphad*, Pune*, Akola, Parbhani, Mahabaleshwar*, Hyderabad*, Dharwar*, Bangalore*, Coimbatore*	1575
Southern Hills	Hills of Southern India	Wellington***	

* AICWIP centers

** Strengthening of existing centers and opening of new centers in potential wheat areas, proposed in 6th Five-Year Plan (1980-85).

*** Off-season summer nursery centers.

b) Agronomy: Agronomic evaluation of new strains under different levels of fertility, irrigation doses, and sowing dates; management of the wheat crop in rice-wheat rotation; effect of cultural practices on weeds; chemical control of weeds; efficacy of microbial cultures, micronutrients, antitranspirants etc. (work on seeding rates, row spacing, depth of planting, critical stages of irrigation, seed bed preparation, minimum tillage etc., has been discontinued as sufficient data already were collected earlier in the project).

c) Pathology: Screening of promising lines against different diseases at hot spots; plant pathological nurseries; trap nurseries; survey and surveillance of diseases; chemical control of diseases; tolerance studies against rusts.

d) Quality: Screening of new strains for different quality attributes; studies on effect of different cultural practices and storage conditions on quality; effect of diseases like karnal bunt on nutritional and other quality characters.

e) Physiology: Evaluation of yield-contributing characters of wheat under different eco-edaphic conditions; studies on temperature responses in wheat; germinability of wheat genotypes at different osmotic concentrations; National Drought Screening Nursery; and development of selection indices to assist breeders.

f) Nematology: Screening of strains against *Heterodera* and *Anguina* nematodes; control of nematodes through chemical/cultural practices; and survey of nematode diseases.

g) Entomology: Control of pests through chemical/cultural practices; screening of varieties for resistance to field pests; and screening of varieties for resistance to stored grain pests.

In addition to these experiments, the AICWIP assists the developmental agencies in organization of adaptive trials, minikit tests, production of breeder and foundation seed of new and commercial varieties, national demonstrations, etc.

Two off-season nurseries are operated, one at Lahaul in the Himalayas, and the other at Wellington in the southern hills. The different centers take full advantage of these.

Results

During the years of its existence the AICWIP developed or isolated a number of varieties for rainfed/irrigated, timely sown/irrigated, and late sown conditions for different parts of the country (Table 7). Out of the 22 million hectares in India now, about 15 million hectares already have been brought under high yielding or improved varieties. Seed of some of these varieties is in demand in other countries as well.

The new semidwarf wheats have exhibited potential to yield as much as 10 tons/ha under well-managed conditions in India, thereby showing the way for future planning. They also have enabled multiple or relay cropping. Some districts are producing a little over 6 tons/ha of food grains per year on the same piece of land.

Each state or a zone has a number of varieties available for cultivation, thus bringing in the needed diversity or mosaic pattern of varietal distribution to act as a protection against widespread occurrence of epidemics. In recent years several seasons were very favorable for widespread occurrence of rusts. There were, however, no widespread epidemics as in the past when large tracts of wheat were destroyed leading to misery to millions of farmers.

Three semidwarf multilines have been developed in the background of Kalyan Sona. Multilines of other high yielding varieties like WL 711, WH 147, HD 2009 are under development. Similarly, mutilines of dwarf durums like HD 4519 and tall durums like Bijaga yellow, NI 146, A 206 are in preliminary yield tests.

Genes or combinations of genes that give protection against Indian races of rusts, powdery mildew, bunt, and Alternaria leaf blight have been identified. At the foci of infection of rusts, resistant varieties are constantly being changed to prevent build up of new races or initial inoculum of existing races. This strategy is paying good dividends.

Chemicals like Vitavax, Benlate, Bavistin, Plantavax, RH 124, Dithane Z-78, etc. have been identified which offer protection against one or the other of the diseases. Similar identification of chemicals has been made for control of nematodes (nemagaon), white ants, army worms, cut worms, etc.

A package of practices for increasing productivity of wheat for different situations has been worked out in detail. Chemicals like Tribunil, Terbutryn, Dosanex, Isoproturon, Tok E-25, etc., have been identified for control of noxious weeds.

Besides the direct benefits in the form of increased wheat production, the impact of new wheats and the technology has led to side benefits resulting in increased gr[illegible]n fertilizer, seed, pesticide, milling and baking industri[illegible]; ground water exploitation through tube wells; devel[illegible] of irrigation projects; storage facilities, etc. The message of wheat spread to other crops also.

Table 7. Varieties recently developed for different zones or states.

Zone	States	Varieties developed
Northern Hill	Hills of U.P., H.P. & Kashmir	Sonalika, Girija, Shailaza, VL 421, HS 86, HB 208, VL 401, VL 404, NP 846
Northern Plains	Jammu, Punjab, western U.P., eastern Haryana, eastern Rajasthan, Delhi, northern M.P.	WL 711, HD 2009, HD 2204, HD 2177, WH 157, WL 1562, Raj 821, Raj 1114, MLKS 11, KSML-3, KML 7406, HD 1981, C 306, IWP 72, WL410, Raj 1482, WG 357, WG 377, Kalyansona, PV 18, Sonalika, UP 310, UP 319, UP 368
North Western	Western Haryana, western Rajasthan, northern Gujarat	WH 147, HD 2009, HD 2204, HD 2177, Raj 821, Raj 1114, K. Sona, Sonalika, J 24, J1-7, C 306, IWP 72, WL 410, HD 1981
North Eastern and Far Eastern	Eastern U.P., northern Bihar, Orissa*	Sonalika, Janak, K 7410, HUW 12, HP 1102, HP 1209, HP 1303, HW 135, UP 115, UP 262, C 306, K 65, NP 852
Central and South Eastern	M.P., southeastern Rajasthan, Bundelkhund area of U.P., southern Gujarat, Coastal A.P.*, northeastern Maharashtra*	Kalyansona, Sonalika, WH 147, HD 2236, Lok 1, HD 784, Meghdoot, NP 404, Hy. 65, Nerbada 4, Nerbada 112, C 306, Raj 911, HD 4530, Jairaj, A9-30-1, J1-7, J 24, A 206, A 624, A 28, Malwa Raj, Shera
Penisular	Maharashtra, Karnataka, western A.P., plains of Tamilnadu	K. Sona, Sonalika, CC 464, HD 2189, NI 747-19, NI 5439, MACS 9, HW 657, Malavika, Bijaga yellow, UP 301, UP 215, Choti Lerma, Safed Lerma
Southern Hill	Hills of south India	HD 2135, HW 517, Choti Lerma, NP 200, Safed Lerma

* Recently shifted to southeastern zone.

The identification and development of appropriate genotypes coupled with the development of suitable production and protection technology by the scientists working in or collaborating with the All-India Coordinated Wheat Improvement Project acted as a catalyst in bringing in several direct and indirect benefits to India. The new varieties and the technology brought considerable stability to our food economy which is often seriously affected by floods, drought, etc. while fully realizing that the next yield jumps will be slower and costlier.

Future Plans

In the coming years priority will be given to narrowing the gap between the gentic potential for yield of already existing wheat varieties and what is being obtained now by the average farmer. While doing so,attempts will be made to reduce the vulnerability of the crop to diseases, drought, and other calamities i.e., further stability in production will be added in our wheat varieties and cultivation practices. This is in line with our realization in India and elsewhere that the next yield jumps will be more slow and costly. However, attempts will continue to increase productivity of the existing genotypes through more efficient plant type or through further spring X spring wheat hybridization or through exploitation of winter wheats. There will be a further increase in wheat area (particularly in the "non-traditional" areas) provided the needed inputs like fertilizers, diesel, electricity, etc. are not limiting. The new durums and the triticales offer good opportunity for further stepping up of yield or bringing in diversity in our cultivation. Wheat quality will be one of the priority items for implementation, not only to meet internal needs, but also to facilitate export. Although the Government of India is giving the highest priority to irrigation, substantial areas will continue to be under rainfed wheat. Work already is being intensified on this aspect. The National Commission of Agriculture in India estimated that the annual wheat needs of the country by 2000 A.D. will be in the order of 50 million tons. It may be possible to achieve this target, even a decade earlier.

Selected References

Anonymous. 1968. Five years of research on dwarf wheats. IARI, New Delhi, India. p. 52.

Anonymous. 1978. Wheat research in India 1966-1976. ICAR, New Delhi, India. p. 244.

Anonymous. 1976. Report of the National Commission on Agriculture, India.

Anonymous. 1979. Fertilizer Statistics 1978-79. Fertilizer Association of India, New Delhi, India.

Randhawa, M.S. 1979. A history of the Indian Council of Agricultural Research. 1929-1979. ICAR, New Delhi, India. p. 510.

Rao, M.V. 1979. The dwarf wheat miracle, what next? Indian Farming. September.

Swaminathan, M.S. 1979. Recent trends in crop improvement in India. Proc. 5th Int. Nat. Wheat Genetics Symp., New Delhi, India. Vol. 2: 1267-1298.

THE TRANSFER OF GREENBUG RESISTANCE FROM RYE TO WHEAT

E. L. Smith and E. E. Sebesta
United States

Abstract

Genetic resistance to biotype C of the greenbug, Schizaphis graminum (Rondani), found in 'Insave F.A.', an Argentine rye, was transferred to wheat via an induced chromosome translocation. This transfer, resulting in the germplasm line, 'Amigo', offers an economic means of controlling this pest in wheat. Amigo possesses a high level of resistance to biotype C but is itself not entirely satisfactory as a candidate cultivar. Greenbug resistant selections from crosses between 'Amigo' and short-strawed cultivars adapted to the southern Great Plains are currently under evaluation. Preliminary tests indicate that several of these selections are particularly promising in terms of overall agronomic chracteristics and bread-making quality. Seed increases and further testing of these selections are under way.

Introduction

The greenbug, Schizaphis graminum (Rondani), is one of the most serious insect pests of wheat in the southern Great Plains of the U.S.A. This aphid constitutes a particularly serious production hazard in Oklahoma where losses to the wheat crop are estimated at 30 million dollars annually. Occasionally, serious outbreaks occur as in 1975 when losses in production and costs of chemical control treatments were set at 90 million dollars. None of the wheat cultivars grown currently has any practical resistance to this pest. There are several species of natural enemies of the greenbug. Some of these increase to large numbers, but usually the buildup of these predators and parasitoids occurs too late in the season to prevent economic losses. The only effective control measure at present is the application of organophosphorus chemicals.

The aphid injects a toxicant into the plant as a part of its feeding process and a relatively small number of greenbugs can cause serious damage. Four biotypes of the greenbug (biotypes A, B, C, D) have been distinguished in Oklahoma (Starks and Burton, 1977). Biotype C, first identified in 1968, has since largely replaced biotypes A and B and is now the predominant biotype found in the southern Great Plains area. Biotype C is able to better withstand high summer temperatures and has a higher reproductive rate than biotypes A and B. Biotype D appears to be similar to C in most respects but is distinguished from it by having resistance to certain insecticides.

A search through the USDA wheat collection failed to reveal

AR-SEA/USDA and Oklahoma State University, Stillwater

any wheats with an adequate level of resistance to biotype B or C of the greenbug. However, Arriaga and Ree (1963), in Argentina, had reported that Insave F.A. rye (Secale cereale) possessed a single dominant gene for resistance to greenbug. Tests in Oklahoma revealed that Insave rye was resistant to biotype B and subsequent tests showed that it was also resistant to biotype C. A project initiated in Oklahoma in 1966 by E. E. Sebesta to transfer greenbug resistance (biotype B) from Insave rye to hexaploid wheat was intensified when biotype C appeared on the scene (Sebesta and Wood, 1977).

Development of Amigo Germplasm

The development of 'Amigo' germplasm has been described previously (Sebesta and Wood, 1978; Sebesta, 1978), so only a brief review of the developmental procedures will be presented here.

Since the transfer of genetic characters from rye to wheat is not possible using conventional breeding methods, chromosome engineering procedures pioneered by Sears (1956) were used in the transfer of greenbug resistance from Insave rye to hexaploid wheat.

Insave was first crossed with 'Chinese Spring' wheat. The chromosome complement of the primary wheat X rye hybrid was doubled with the use of colchicine to produce the amphiploid (octoploid triticale) which was later released as a germplasm line under the name of 'Gaucho'. The amphiploid was then crossed to wheat and the resulting hybrids screened for resistance to the greenbug in flat tests in the greenhouse.

Spikes from the resistant plants were X-rayed at the mature pollen stage and used to pollinate emasculated wheat plants. Tests for resistance were made on the X_1 and X_2 progenies. Based on segregation patterns (3 resistant:1 susceptible) in the X_2, several putative translocations were identified. X_3 populations were tested for resistance and analyzed cytologically. Resistant plants having 21 pairs of chromosomes were again crossed with wheat. Cytological studies were made on these F_1's while tests for resistance to the greenbug were made on F_2 families. One agronomically promising line (X-ray pollen grain family 73R132) showed 21 pairs of chromosomes in the F_1 and gave a good fit to a 3:1 ratio, verifying the transfer of resistance from rye to wheat.

A composite of 30 homozygous resistant X_5 lines of the 73R132 series was released as a germplasm line in 1976 under the name 'Amigo', (C.I. 17609). Amigo is a red-seeded winter wheat with 21 pairs of chromosomes. Observations indicate the basis of resistance to the greenbug is a combination of antibiosis and tolerance. It carries a chromosomal translocation from Insave rye which confers resistance to greenbug biotype C. Because of its normal cytological and breeding behavior, Amigo can be easily manipulated using conventional breeding procedures.

In addition to greenbug resistance, observations indicate that it is resistant to powdery mildew, the wheat curl mite, and the English grain aphid. There are no wheats in the pedigree of Amigo which confer resistance to these pests, so by inference it is concluded that the translocated rye segment is responsible. The linkage between greenbug resistance and resistance to powdery mildew appears to be complete and selection for greenbug resistance in segregating progenies has, in some instances, been made on the basis of mildew reaction. So far, this technique has been completely effective. Seed of Amigo germplasm has been distributed to 59 breeding programs around the world.

Use of Amigo Germplasm in the Oklahoma Program

Amigo itself is not entirely satisfactory as a commerical variety for the southern Great Plains area. It has some limitations in yield potential and bread-making quality. Moreover, it is a tall-statured type with a tendency to lodge. However, as germplasm, it provides the breeder with a pest resistance gene in a wheat background without barriers (so far as is known) to combining this characteristic with high grain yield potential, short stature, acceptable quality and other desirable traits.

In the series of crosses made with family 73R132 (Amigo) to confirm the segregation pattern of greenbug resistance, several short-strawed cultivars were used. Among these were TAM W-101 and Payne. The greenbug resistant plants from the F_2 populations of these crosses were saved and grown to maturity in the greenhouse in 1976. The following year, some 2500 F_3 plant rows were grown in the field at Stillwater and concurrent greenbug tests were conducted in the greenhouse to identify lines homozygous for greenbug resistance. Based on field appearance (maturity, height, vigor) and greenbug reaction, 50 F_3 progeny rows were selected for replicated testing in 1978 as F_4 lines.

These 50 F_4 lines (F_2 sub populations) were evaluated in 2-row plots at 3 locations in the state with 2 replications per location. Ten standard cultivar checks were included for comparison. Data were collected on agronomic characteristics, leaf rust reaction and micro-quality analysis. Eleven of the 50 F_4 lines had yields in the range of the best cultivar checks and seven of these had satisfactory scores for quality. Straw strength of these lines was better than that of Amigo (Smith and Sebesta, 1978). Five of these lines were crosses with TAM W-101 and two of them were from crosses with Payne.

In 1979, these seven lines were evaluated in replicated tests at five locations in the state. Plots were 4-3 m rows and each test had 4 replications. Based on agronomic and quality data obtained from these tests, three of the greenbug resistant lines, OK78002 (TAM W-101 X Amigo), OK78047 (Payne X Amigo), and OK78058 (Payne X Amigo) appeared particularly promising. These three lines

compared rather favorably in grain yield with the best standard cultivar checks in the absence of greenbug damage (Table 1).

Table 1. Grain yields (kg/ha) of greenbug resistant wheat strains and standard cultivar checks (Oklahoma, 1979).

Cultivar	Lahoma	Woodward	Still-water	Goodwell	Haskell	Average
TAM W-101	4365	5051	4856	5899	3968	4829
OK78002	4029	5172	4809	6504	3639	4829
Vona	4116	5360	4554	6968	3114	4823
Newton	3645	4937	4627	7190	3652	4809
OK78047	3161	4204	4668	6827	4358	4641
OK78058	3323	4540	4742	6504	4089	4641
Payne	3639	3995	4271	6410	4264	4513
Triumph 64	3195	3612	4163	4917	3316	3841
$\bar{X}$ 1/	3545	4486	4547	6309	3746	4527
LSD .05 2/	323	605	498	545	491	--
C.V. 2/	6.3	9.1	7.7	6.1	9.5	--

1/ Mean of the 8 entries shown above.
2/ LSD and C.V. based on all 30 entries in the tests.

These lines, OK78002, OK78047, and OK78058 had average yields of 4829, 4641, and 4641 kg/ha, respectively, compared to TAM W-101, Vona, Payne, and Triumph 64 (long-term check) with yields of 4829, 4823, 4513, and 3841 kg/ha, respectively.

Agronomic data for these three lines, along with five cultivar checks are presented in Table 2. OK78047 and OK78058 exhibited relatively high test weight scores while OK78002 was somewhat lower but still within the acceptable range. OK78047 and OK78058 had heading dates equal to that of Payne (mid-early), while OK78002 was several days later (Newton class). OK78002 is a semi-dwarf (TAM W-101 height class) and OK78058 is mid-tall (slightly taller than Newton). OK78047 is tall-statured (102 cm compared to 96 cm for Triumph 64). All three greenbug lines had higher post-maturity shattering scores than TAM W-101, Vona, Newton, or Payne.

Table 2. Agronomic data of greenbug resistant wheat strains with comparisons (Oklahoma, 1979).

Cultivar	Average yield	Test weight	Relative heading	Plant height	Lodging score	Shatter score
	(kg/ha)	(kg/kl)	(days)	(cm)	(%)	(1-9)
TAM W-101	4829	77.7	37	83	02	2
OK78002	4829	76.5	38	84	05	3
Vona	4823	77.9	32	82	05	1
Newton	4809	78.0	38	89	10	2
OK78047	4641	79.7	35	102	15	3
OK78058	4641	78.5	35	90	05	5
Payne	4513	76.7	35	86	10	2
Triumph 64	3841	79.5	33	96	15	4

OK78002 and OK78058 appear to be satisfactory in terms of bread-making quality (Table 3). There may be some question about OK78047 because of its short dough-mixing time. Its mixogram score (2-2/8 min.) was slightly lower than that of Triumph 64 (2-4/8 min.), and Triumph 64 is considered to be at the low end of the acceptable range for mixing time. Additional quality evaluations will be conducted following the 1980 harvest.

Table 3. Representative quality data of greenbug resistant wheat strains and check cultivars (O.A.E.S. Quality Lab., 1979).

Cultivar	% Protein		% Flour yield	Mixogram (min.)
	Wheat	Flour		
TAM W-101	12.0	10.2	64.0	3-2/8
OK78002	10.9	9.2	66.4	3-4/8
Vona	11.0	10.1	59.2	3-6/8
Newton	11.4	9.9	68.8	3-6/8
OK78047	11.7	10.1	66.4	2-2/8
OK78058	11.4	10.5	65.6	3-4/8
Payne	12.0	11.3	60.8	2-6/8
Triumph 64	12.3	10.8	64.8	2-4/8

Seed increases of these three lines have been initiated and more extensive testing is under way. It is anticipated that one or more of these lines will be considered for release to growers this year.

References

Arriaga, H. O. and R. R. Ree. 1963. Comportamiento hereditario de la resistencia a la toxemia del pulgon verde en centano, cebada y trigo. Rev. Fac. Agron., Univ. Nac. La Plata (Terecere epoca) 39:37-50.

Sears, E. R. 1956. The transfer of leaf rust resistance from Aegilops umbellulata to wheat. Brookhaven Symp. Biol. 9:1-22.

Sebesta, E. E. and E. A. Wood Jr. 1977. Origin of Amigo (C.I. 17609) greenbug resistant germplasm. Proc. 14th Hard Red Winter Wheat Workers Conf. pp. 55-56. (Abstract)

Sebesta, E. E. 1978. Chromosome engineering: Strategies in breeding for greenbug resistance in wheat. Proc. 3rd Biennial Host Plant Resist. Workshop. (Abstract) Gainesville, FL.

Sebesta, E. E. and E. A. Wood Jr. 1978. Transfer of greenbug resistance from rye to wheat with x-rays. Agron. Abstracts. pp. 61-62.

Smith, E. L. and E. E. Sebesta. 1978. Agronomic and quality characteristics of winter wheat lines resistant to the greenbug (Schizaphis graminum). Agron. Abstracts. p. 62.

Starks, K. J. and R. L. Burton. 1977. Greenbugs: Determining biotypes, culturing, and screening for plant resistance. USDA Tech. Bul. 1556.

SELECTING SUPERIOR WINTER WHEAT CROSSES AND LINES IN EARLY GENERATIONS

Z. Kertesz, J. Matuz and Z. Barabas
Hungary

Abstract

A followup study on a top cross series gave evidence that superior crosses can be identified by measuring their F_1 performance, heterosis and combining ability. Combining ability studies of F_2 and F_3 generations add weight to the above statement.

Numerical components measured on space-planted F_2-F_3 generations are rather unreliable in selecting superior lines from any population. Only harvest index and kernel weight per head can be regarded as selection criteria in these generations.

Factor analysis and factor regression showed that an intervallum of the harvest index and kernel weight can be used as selection criteria for the yield of the succeeding generations. Close parabolic regression was found between the factor involving the harvest index and the yield of the succeeding generations grown at normal seeding rate.

A selection system based on these traits and indices is discussed.

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Every breeder has a concept in selecting parents for crossings which will produce successive populations as close as possible to the breeding target. And when once the desirable populations have been obtained he tries to find an effective selection system to identify superior plants and lines not later than in the F_2-F_3 generations. To achieve these aims, during the past ten years we have conducted a series of diallel analyses to estimate the value of parents and crosses from the point of view of breeding (Matuz et al. 1974, Barabas et al. 1976). The present work deals with the evaluation of the utility of the principal component analysis, complemented with F_1-F_3 tests, heterosis and combining ability estimates, in selecting superior crosses and lines in early generations.

For the F_1 experiments 11 female and 10 male parents were mated in factorial fashion. The mating system can be seen in Figure 1. F_1 hybrids along with their parents were tested in a dense microplot (400 seeds/m^2) and in a space-planting (20 seeds/m^2) experiment with four replications. Hybrids in the fenced-in area were tested over 3 years (1977-1979) and the others for one year. To avoid edge and side effects male sterile puffer rows were used.

Cereal Research Institute, Szeged

Figure 1. Mating system of parents.

			M	A	L	E	S					
			6	7	8	9	10					
			GKF 2	Sv	Prt	Sdv	Rbn	Dl	TpR	Rna 2	Goya	Mut 48
FEMALES	1	Jbj 50	+	+	+	+	+	+	+	+	+	+
	2	Jkm	+	+	+	+	+	+	+	+	+	+
	3	Oqt	+	+	+	+	+	+	+	+	+	+
	4	Rn 47	+	+	+	+	+	+	+	+	+	+
	5	Lut	+	+	+	+	+	+	+	+	+	+
		F 26.70	+	+	+	+	+	+	+	+	+	+
		Mv 4	+	+	+	+	+	+	+	+	+	+
		Grana	+	+	+	+	+	+	+	+	+	+
		Trio	+	+	+	+	+					
		Dana	+	+	+	+	+					
		Bzt						+	+	+	+	+

Yield, yield components, and some other yield-related characteristics, 9 traits in all, were measured and/or calculated. Combining ability analysis was carried out following design II of Comstock-Robinson (1952). In the principal component analysis and regression we used the methods of Kendall (1978) in Svab (1979).

According to the yield tests over 3 years (see Table 1) the best parent was Sadovo Super followed by Ogosta, and the poorest were Rannaja 47 and Jakometti. Average performance of the parents was 57g, of the best parent 70g. Mean of the hybrids was 62g and the best hybrid gave 86g/plot at a high seed rate.

For combining ability, (see Table 2). GCA effects also show that Ogt was the best combiner improving the yield of its hybrids by 9g, about 30% on average. According to the results of these trials, parents with good combining ability have good per se performance as well and their hybrids give significant heterosis for the best parent. We agree with Wienhues (1968) and others that heterosis implies a good prospect for selection, but the yield level of the parents and hybrids also must be considered.

Table 1. Average values for grain yield and its primary components in F_1 test.

	Grain yield per plot g	Spike per plot No.	Kernels per spike No	1000-kernel weight g
Parents	57.0	46.0	32.0	39.0
F_1	72.0	48.5	35.4	42.0
Best parent	70.0	54.5	32.5	39.5
Best F_1	86.0	53.0	38.0	43.0

Table 2. Per se performance, GCA effects of extra parents, and average heterosis with the given parent common.

Parents	No.	Yield g/plot	GCA effect	Average heterosis for the best parent
Sdv	P_9	70.0	4.92	9.30
Ogt	P_3	68.0	9.43	15.70
GKF 2	P_6	59.0	2.83	6.30
.				
.				
.				
Rbn	P_{10}	54.0	- 4.17	- 3.70
Rn 47	P_4	51.0	-10.44	-12.61

Principal component analysis provided some further information for selecting parents and superior crosses. It grouped the traits according to their relationships. In the analysis of the parents and F_1's the first principal component was composed of the biological yield, grain yield, harvest index, seeds/plot and grain yield/spike. Principal component 2 consisted of seeds/spike and kernel weight.

In calculating principal component values for each parent and hybrids we came to the following conclusions (Figure 2):

Parent 3 (Ogosta) and P_9 gave the best combinations as was predicted by the GCA values.

Diverse parents for the main yield components e.g. 3 and 7 will give superior crosses (see hybrid 37, Ogt-Sv). Ogosta has large but fewer kernels/spike and reverse.

Close parents in principal component value e.g. 4 and 10 give poor hybrids (see hybrid 410, Rn 47-Rbn).

On the C_1 scale the rank in principal component value of the hybrids was almost the same as their rank in yield and heterosis for the best parent.

By means of principal component values high-yielding crosses can be predicted with a known relationship between the yield components. On the left-hand side of the figure hybrids will have large but fewer kernels/spike and on the right-hand side the reverse.

After obtaining excellent crosses comes the second serious problem of getting superior lines in early generations. We agree with McGinnis-Shebeski (1968), that selection on a single plant basis at F_2 is generally ineffective.

From each of five space-planted F_2 populations consisting of 3000 plants, 300 plants were selected at random. The same 9 traits were measured as in the F_1 tests. Each F_3 progeny was tested at a high seed rate of 500 seeds/m^2. From the middle sector of the plots, samples were taken and the same traits measured. Some results and conclusions:

There was no significant correlation between the traits measured on space -planting F_2 and the stand F_3 yield (Table 3). So none of the traits measured on spaced plants proved to be an acceptable selection criterion.

Principal component analysis provided better information about the correlation structure of the populations than simple correlations. It grouped the traits as in Table 4.

I. Principal component:	biological yield, grain yield, and spikes and kernels/plant.
II. Principal component:	harvest index, seeds/spike, and grain yield/spike.
III.Principal component:	1000-grain weight and plant height.

Correlations between principal component value of the F_2 plants and crop yield of their progenies (r=0.05) showed that even principal component regression was not suitable for predicting the crop yield of the F_3 lines.

Figure 2. Principal component values of some parents and F_1's.

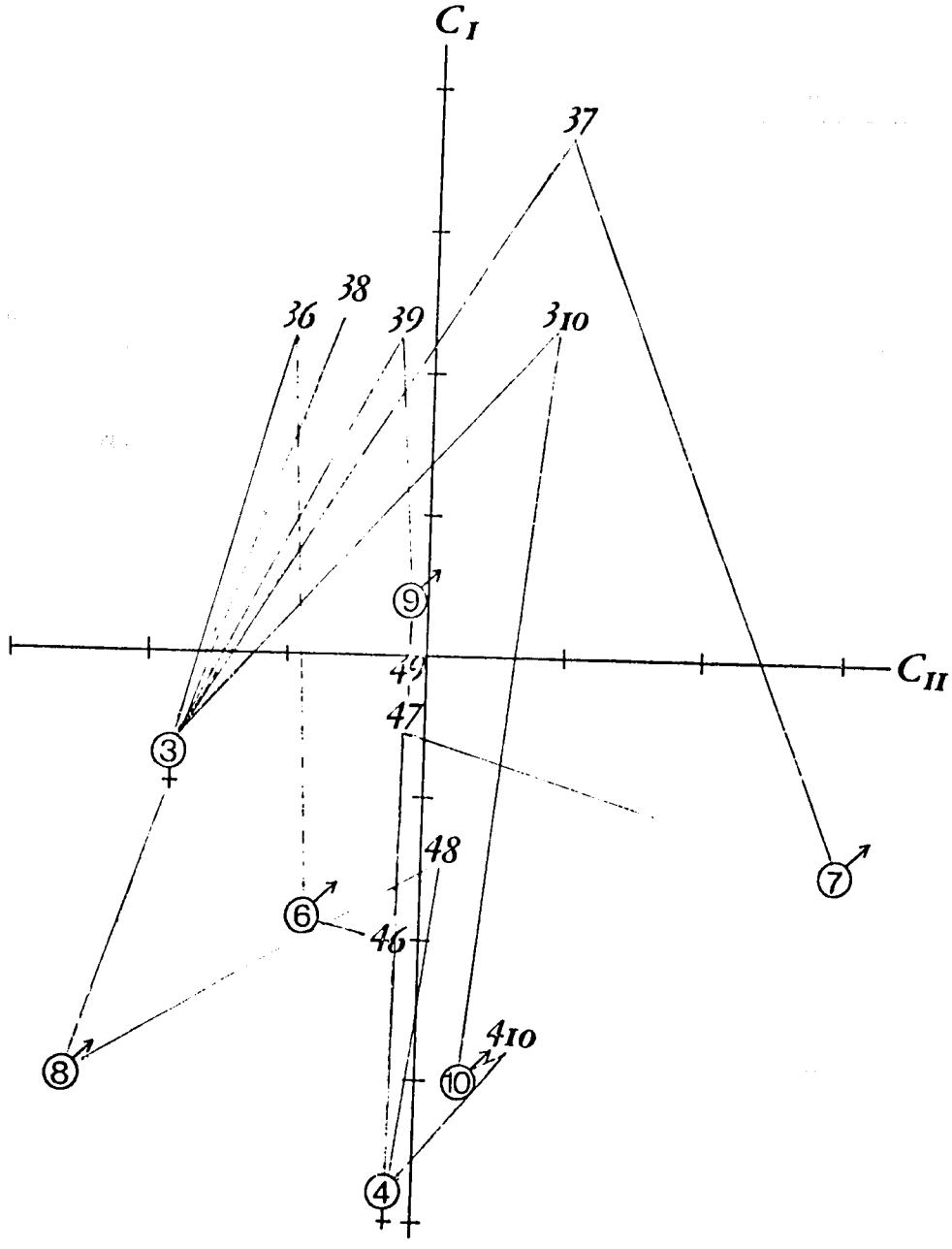

Table 3. Correlations between the traits of spaced F_2 and the stand F_3 yield in 2 combinations.

Traits	Ogt-Prt	Ogt-Rbn
Plant height	0.303	0.191
Biological yield/plant	0.125	0.193
Grain yield/plant	0.140	0.200
Spikes/plant	0.049	0.132
1000 kernel weight	0.204	0.153
Harvest index	0.075	0.053
Grains/plant	0.042	0.124
Grains/spike	0.001	- 0.004
Grain yield/spike	0.134	0.094

Table 4. Result of principal component analysis from F_1 test.

	Principal component weights				
	C_I	C_{II}	C_{III}	C_{IV}	C_V
Plant height	NS	NS	-0.632	NS	NS
Biological yield/plant	-0.926	NS	NS	NS	NS
Grain yield/plant	-0.987	NS	NS	NS	NS
Spikes/plant	-0.757	NS	NS	NS	NS
1000 kernel weight	NS	NS	-0.673	NS	NS
Harvest index	NS	-0.637	NS	NS	NS
Seeds/plant	-0.933	NS	NS	NS	NS
Seeds/spike	NS	-0.560	NS	NS	NS
Grain yield/spike	NS	-0.871	NS	NS	NS
i	3.875	2.430	1.369	0.693	0.598
Percentage of total variation %	43.23	27.11	15.27	7.73	6.67

For the next cycle of the selection in F_3 drilled trials with selecting lines sown in high seed density we again need selection criteria. Yield itself or its components can be such a predictor. The results of our experiments showed that principal component values calculated for each F_3 line gave a close correlation with the F_3 plot yield r=0.855.

Further examinations are needed to clarify whether principal component values may be predictors of the F_4 yield. If so, we would be able to select lines superior in yield with desirable correlations between yield components.

References

Barabas, Z., Kertisz, Z., Matuz, J. 1976. Selection of early generations in cereals. (German) Bericht uber die Arbeitstagung 1976 der Arbeitsgemeinschaft der Saatzuchtleiter in Gumpenstein vom 23. bis 25. Nov. 1976.

Comstock, R.E., Robinson, H.F. 1952. Estimation of average dominance of genes. Heterosis. Ed. J.W. Goven. Ames: Iowa State College Press. 491-516.

Matuz, J., Paradi, L., Schultz, M., Barabas, Z. 1974. General and specific combining ability in winter wheat at two plant densities. Cereal Res. Comm. 2:175-183.

McGinnis, R.C., Shebeski, L.H. 1968. The reliability of single plant selection for yield in F_2. Proc. 3rd Int. Wheat Genet. Symp. Australia 109-114.

Svab, J. 1979. Tobbvaltozos modszerek a biometriaban. Mezogazdasagi Kiado, Budapest.

Wienhues, F. 1968. Long-term yield analysis of heterosis in wheat and barley. Variability in heterosis, fixation of heterosis. Euphytica 17. (Suppl.1):49-62.

USE OF GENERAL COMBINING ABILITY ESTIMATES TO PREDICT PROGENY PERFORMANCE FOR PLANT HEIGHT AND GRAIN YIELD IN WHEAT (*Triticum aestivum*)

W. E. Kronstad and V. Petpisit
USA

Abstract

Concerns are being expressed that yield plateaus have been reached in the major crop species including wheat. If further increases in food production per hectare are to be realized, improved management systems and cultivars which respond to such cultural practices must be developed. In breeding superior wheat cultivars, more usable genetic variability must be created and used in a more efficient manner. If the breeder could predict, without having to make the actual crosses, which parental combinations would result in the highest frequency of desirable plants in subsequent segregating populations, a large measure of efficiency could be achieved. It would also be important if such information could be applied to determine the most productive sequence in which to make three- and four-way crosses. With more than 35,000 potential parents in the world wheat germplasm the choice of which cultivars to use and in what sequence in difficult, especially for quantitatively inherited traits such as grain yield.

Several methods of identifying favorable hybrid combinations in corn have been successfully employed. In the Oregon State University cereal program a number of these approaches have been investigated in wheat using diallel crosses and tester stocks. One of the methods of predicting parental performance that appears the most promising is the use of Combining Ability Analysis. It has been observed that crosses involving cultivars which had been previously found to have high individual General Combining Ability Effects produced a higher percentage of superior yielding progeny in subsequent generations. This was true for several simply inherited traits and for grain yield. When three and four-way crosses were evaluated, the individual General Combining Ability Effects for the possible parents were again useful as predictors of both the potential of a cross and also in determining the most productive sequence in which the crosses should be made.

Diallel crosses have proven useful in obtaining combining ability estimates; however, selected testers which themselves have high General Combining Ability Effects may also be used as a means of identifying the most promising combinations thus reducing the number of crosses needed.

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Oregon State University, Corvallis

A greater degree of efficiency would be achieved if plant breeders could predict which parental combinations would result in the greatest frequency of desirable progeny. This would also be true in determining the most productive sequence in which to make three-and four-way crosses. When the breeder is concerned with qualitatively inherited traits, the choice of which parents to hybridize is obvious. However, when a quantitatively inherited trait like increased grain yield is the objective, the choice of parental combinations is much more difficult.

Several methods of identifying favorable parental combinations in corn have been successfully employed. One method, the use of combining ability analysis has proven to be particularly useful in predicting the performance of hybrids based on the known combining ability of available inbred parents. This paper reports the use of General Combining Ability (GCA) estimates as a means of predicting parental performance in wheat for plant height and grain yield.

Five high yielding and genetically diverse winter wheat cultivars were selected as the experimental material. These included: 1) 'Yamhill', a mid-tall cultivar developed from the cross Heine VII/Alba; 2) 'Stephens', a semi-dwarf cultivar resulting from the cross Nord Desprez/Pullman Selection 101; 3) 'Daws', a semi-dwarf cultivar originating from the cross CI 1484//CI 13645/PI 178383; 4) 'Maris Hobbit', a short-strawed cultivar developed from the cross 'Professeur Marchal'//Marene Desprez/VG 9114//TJB 16, and 5) 'Druchamp', a mid-tall cultivar resulting from the cross Vilmorin 27/Fleche d'Or.

Plant height and grain yield on an individual plant basis were obtained from a diallel cross involving the five parents, F_1's and all possible three- and four-way crosses. The experimental populations were planted in randomized block with 150 entries representing five parents, ten F_1's, ten F_2's from single crosses and 30 F_1's, 30 F_2's from three-way crosses and 15 F_1's, 15 F_2's from from four-way crosses. The population included 20 plants per entry for the parents and F_1's of the single crosses, 50 plants for F_2's of single crosses, and F_1's and F_2's of three- and four-way crosses. Data from the F_1's were used to determine the relative GCA effect of the individual parents. A total of two replications were grown at two locations. The material was analyzed for each site and combined where no significant interactions were observed for GCA. In this paper only the results from one location will be presented. Combining ability estimates were obtained using Model 1, Method 4 as proposed by Griffing (1956).

Since the breeder of self-pollinating species is restricted to that portion of the total genetic variation that behaves in an additive manner, only the GCA estimates will be considered. In Table 1 the expected mean squares for both GCA and Specific Combining Ability (SCA) are presented based on the performance of the F_1 generation. It can be observed that the GCA for plant height was significant at the one percent level. This was not

true for grain yield, however. Perhaps this lack of significant GCA estimates reflects the fact that all five of the parental lines were high yielding. Despite this lack of significant observed mean squares for grain yield, the individual GCA effects of the parents were obtained for both plant height and grain yield.

Table 1. Observed mean squares for General and Specific Combining Ability for the F_1 populations.

Source	DF	Plant Height	Grain Yield
GCA	4	221.64**	15.70
SCA	5	17.18	9.24
Error	180	0.79	14.72

*Significant at the five percent probability level.
**Significant at the one percent probability level.

These results are provided in Table 2 for the five cultivars. For plant height, which is generally regarded as a qualitatively inherited trait, Druchamp (11.55) and Yamhill (3.56) had the greatest individual effect. Perhaps this would be expected as they were the tallest parents used in the study. Maris Hobbit being a dwarf cultivar, had the lowest GCA effect (-11.70). When grain yield is considered, Maris Hobbit (3.07), followed by Daws (1.45) contributed the highest GCA effects. The lowest values were noted for Yamhill (-1.63) and Druchamp (-2.58). The relative performance of the F_1 and F_2 population means for the high, intermediate and low GCA parents in various combinations are shown in Table 3 for plant height. With the exception of the high x high and high x intermediate GCA parents, there is good evidence that the high GCA parents contribute more to plant height in subsequent generations. A similar c omparison is made for grain yield in Table 4. Even though a significant difference for GCA was not observed, it is interesting to note that a similar pattern as for plant height emerges. There was some discrepancy; however, the general trend was toward the high and intermediate GCA parents contributing more to grain yield in the resulting progeny. The lowest grain yield in both F_1 and F_2 populations was from the cross Yamhill x Druchamp (67.83 and 62.01, respectively). These represent the two lowest parents in terms of their individual GCA effects.

Table 2. Estimates of General Combining Ability effects for plant height ($_1g_i$) and grain yield ($_2g_i$) for five parents.

Parents	General Combining Ability	
	$_1g_i$	$_2g_i$
Yamhill	3.56	-1.63
Stephens	-3.54	-0.30
Daws	0.13	1.45
Maris Hobbit	-11.70	3.07
Druchamp	11.55	-2.58
S.E. $(g_1 - g_j)$	0.72	3.13

Table 3. Performance of F_1 and F_2 populations from single crosses where the parents had different General Combining Ability effects for plant height.

Crosses	Plant Height (cm) F_1	F_2
High x High GCA		
Druchamp x Yamhill	112.11	106.72
High x Intermediate GCA		
Druchamp x Daws	114.37	110.01
Intermediate x Intermediate GCA		
Daws x Stephens	92.82	98.08
Intermediate x Low GCA		
Daws x Maris Hobbit	91.01	88.25
Low x Low GCA		
Maris Hobbit x Stephens	88.44	86.51

Table 4. Performance of F_1 and F_2 populations for single crosses between parents with different individual GCA effects for grain yield.

Crosses	Average Grain Yield (gm per plant) F_1	F_2
High x High GCA		
Maris Hobbit x Daws	79.32	73.88
High x Intermediate GCA		
Maris Hobbit x Stephens	82.51	67.16
Intermediate x Intermediate GCA		
Daws x Stephens	74.18	74.03
Intermediate x Low GCA		
Stephens x Druchamp	76.76	68.48
Low x Low GCA		
Yamhill x Druchamp	67.83	62.01

When three way crosses are considered for plant height (Table 5), the greatest effect in both the F_1 and F_2 populations was realized when the highest GCA parents (Druchamp or Yamhill) or the lowest (Maris Hobbit) are used as the third parent. Since the third parent is responsible for 50% of the genetic material comprising the three-way cross, such an effect might be expected for a qualitatively inherited trait like plant height. In Table 6, the F_1 and F_2 data are presented for grain yield. Where either Maris Hobbit or Daws were used as the third parent a higher mean value was generally observed. These two parents had the highest GCA effect for grain yield. Conversely, where Druchamp was the third parent, the resulting populations reflected a low mean value in keeping with the low GCA effect of Druchamp for grain yield.

When four-way crosses were considered, the sequence in which the crosses were made was less important than the sum total of the individual GCA effects. This was true for both plant height and grain yield.

Table 5. Performance of F_1 and F_2 populations from three-way crosses where the parents had different General Combining Ability effects for plant height.

Crosses	Plant Height (cm)	
	F_1	F_2
Maris Hobbit/Daws//Druchamp	108.23	99.90
Maris Hobbit/Druchamp//Daws	98.99	101.06
Druchamp/Daws//Maris Hobbit	94.09	95.67
Yamhill/Daws//Maris Hobbit	91.98	87.81
Yamhill/Maris Hobbit//Daws	100.25	97.76
Maris Hobbit/Daws//Yamhill	102.02	101.05

Table 6. Performance of F_1 and F_2 populations from three-way crosses where the parents had different General Combining effects for grain yield per plant.

Crosses	Grain Yield Per Plant	
	F_1	F_2
Maris Hobbit/Daws//Stephens	75.73	69.94
Maris Hobbit/Stephens//Daws	77.18	73.37
Stephens/Daws//Maris Hobbit	77.93	73.60
Yamhill/Druchamp//Daws	78.68	65.58
Yamhill/Druchamp//Maris Hobbit	78.03	70.87
Daws/Maris Hobbit//Druchamp	71.39	61.60

From the results of this study it would appear that the partitioning of individual GCA effects for potential parents may be an effective means of predicting subsequent progeny performance. This was particularly true for single and three-way crosses for plant height. Since there were no significant differences at the five percent level for the expected mean squares associated with GCA, caution must be used in drawing conclusions from this data. Subsequent research findings (Brajcich, 1980) where significant GCA estimates were obtained for grain yield support the trends seen in this study. Individual GCA effects for a quantitatively inherited character like grain yield then appear promising in predicting the most productive parental combinations in wheat.

References

Brajcich, P. 1980. Nature of inheritance, genotype-environment interaction and association among selected agronomic reputed characters in crosses of winter x spring wheat (Triticum aestivum L. em Thell). Ph.D. Thesis, Oregon State University. Corvallis, Oregon.

Griffing, B. 1956. Concept of general and specific combining in relation to diallel crossing systems. Australian Journal of Biological Sciences 9:463-493.

Petpisit, V. 1980. Progeny tests for predicting grain yield and selected agronomic traits in single, three-way and double crosses in wheat. Ph.D. Thesis, Oregon State University. Corvallis, Oregon.

COMBINING ABILITY FOR GRAIN YIELD IN F_1-F_6 GENERATIONS OF DIALLEL WHEAT CROSSES

I. Mihaljev
Yugoslavia

Abstract

The estimation of combining ability over successive generations can greatly help the breeder to judge the reliability of early generation estimates for predicting the potential of the crosses in the advanced generations. The purpose of this study was to obtain information on the nature of combining ability for grain yield over successive generations.

Eight diverse wheat cultivars were crossed in all possible combinations excluding reciprocals. The parents and F_1-F_6 hybrids were tested under rainfed field conditions at Novi Sad in a randomized block design providing three replications each year of testing. Data on grain yield were collected on a plot basis. The combining ability analysis was made using Griffing's (1956) method 2, model I.

The results obtained showed that the relative magnitude of general combining variances was much higher than that of specific combining ability variances over successive generations. GCA effects were quite consistent over generations while SCA effects were not. The importance of these findings for wheat breeding is discussed. The possibility of making reliable general combining ability estimates in the F_2 generation, and that crossing of desirable segregants in the early segregating generations could create the broader variability and accumulations of additive genetic effects have been suggested.

Introduction

The most important information the breeder needs for developing wheat cultivars superior in agronomic characters and for the choice of the most efficient breeding procedure to accomplish this aim is knowledge about combining ability of different wheat genotypes which could have potential use in a breeding program and the knowledge of the genetic systems controlling the characters to be improved. Since grain yield is among the most important and complex agronomic traits it is essential to obtain reliable combining ability estimates for yield.

Combining ability for grain yield in wheat is usually studied in the F_1 generation (Kronstad and Foote, 1964; Brown et al., 1966; Gyawaly et al., 1968; Paroda and Joshi, 1970; Bitzer and Fu, 1972; Virk and Aulakh, 1975; Ketata et al., 1976, and others), but there

Faculty of Agriculture, Novi Sad

are a limited number of reports regarding combining ability studies over successive generations (Bhullar et al., 1979). Since it is difficult with hand emasculation and pollination to obtain sufficient quantities of crossed seeds for a replicated test over different environments, the estimates are usually calculated on the basis of a test at one location and, therefore, they may be rather biased. If an advanced generation combining ability analysis would provide identical results with that of F_1 generation, the crosses could be studied for combining ability in that generation instead of in F_1 and, because of sufficient quantities of seed for testing over different environments, reliable combining ability estimates could be obtained. With this in mind, the present study was designed to investigate the nature of combining ability for wheat grain yield over successive generations.

Materials and Methods

Eight diverse wheat cultivars were used in the investigation. Six of them were winter wheats (Sava, Bezostaia 1, Kavkaz, Libellula, NS-732, N.lot-1) and two were spring wheats (Cajeme 71 and Siete Cerros). These were crossed by hand in all possible combinations excluding the reciprocals.

The eight parents and the resulting 28 F_1-F_6 hybrid combinations were tested under rainfed field conditions at the Experimental station of the Institute of Field and Vegetable Crops at Novi Sad in a randomized block design providing three replications each test year (1973-1978). The plot unit was 0.2 m^2 (one row, 1 m long, 0.2 m between the rows) in the F_1 generation and 1 m^2 (five rows 1 m long, 0.2m between the rows) in F_2-F_6 generations. The sowing density resulted from hand-sowing 375 viable seeds per 1 m^2 each year.

The hybrids and their parents were hand harvested within each replication and measurement of grain yield per plot made each year. Observations recorded for the F_1 generation were mathematically transformed to 1 m^2 for statistical analysis in order to make direct comparisons.

Estimates of general combining ability (GCA) and specific combining ability (SCA) were obtained using Griffing's (1956) combining ability analysis, method 2, model I.

Results and Discussion

The analysis of variances for grain yield progeny means over successive generations showed highly significant differences ($P<0,01$) between the genotypes (hybrids and parents) indicating that a diallel analysis might consequently be performed in each generation (Table 1).

Grain yield means of the parents exhibited large variation in each year of testing; also, the same parent varied considerably from

year to year. Out of the eight parental varieties the winter wheats Sava, Kavkaz and Bezostaia 1 showed the highest potential for grain yield; the spring wheats Siete Cerros and Cajeme 71 and the winter wheat NS-732 the lowest (Table 2).

Table 1. Analysis of variance for progeny means for grain yield in wheat over successive generations.

Source of variation	d.f.	Mean squares					
		F_1	F_2	F_3	F_4	F_5	F_6
Blocks	2	4.859	6.761	17.312	26.802	1.490	5.293
Progenies	35	19.976**	21.883**	10.238**	31.385**	18.991**	7.961**
Error	70	2.494	7.215	3.136	4.598	9.269	3.814

**, * Significant at 1% and 5% level, respectively.

Table 2. Parental means for grain yield in g/1 m^2 (1973-1978).

Cultivar	1973	1974	1975	1976	1977	1978
1. Sava	489	697	733	772	1.083	467
2. Bezostaia 1	536	666	613	618	1.120	937
3. Kavkaz	524	742	737	700	1.007	460
4. Libellula	439	691	635	658	1.027	433
5. Cajeme 71	321	671	645	487	953	383
6. Siete Cerros	457	789	603	457	977	267
7. NS-732	284	554	630	618	1.113	353
8. N. lot-1	419	566	470	492	1.023	383
LSD .05	81	139	91	111	157	101
.01	108	184	122	147	209	134

Combining ability - The analysis of variance for combining ability for grain yield showed that GCA variances were highly significant and higher than SCA variances over successive generations, while SCA variances were not significant in all successive generations (Table 3). This indicates the predominance of additive (fixable) gene effects in the genetic control of grain yield among parents used in the diallel crossings. Numerous investigators have reported GCA variances to be significant and of higher magnitude than SCA variances (Kronstad and Foote, 1964; Brown et al., 1966; Giawaly et al., 1968; Bitzer and Fu, 1972; Virk and Aulakh, 1975; Bhullar et al., 1979 and others), while Paroda and Joshi (1970) found SCA variances to be predominant for grain yield in wheat.

Table 3. Analysis of variance for combining ability for grain yield in wheat over successive generations.

Source of variation	d.f.	Mean squares					
		F_1	F_2	F_3	F_4	F_5	F_6
GCA	7	23.354**	29.054**	9.515**	34.938**	38.933**	7.294**
SCA	28	2.485**	2.154	1.884	4.333*	6.912*	1.496
Error	70	831	2.405	1.045	1.533	3.090	1.721

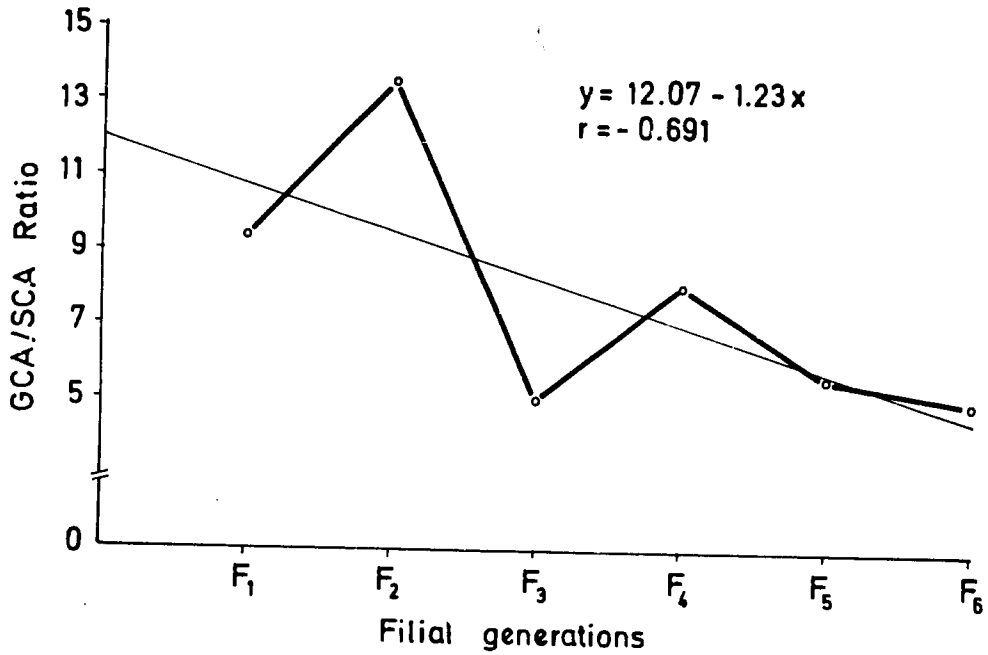
**, * Significant at 1% and 5% level, respectively.

Of particular importance to the wheat breeder intending improvement of grain yield is the predominance of additive gene action for this trait, because it suggests that the improvement can be achieved through the pedigree method of breeding from which superior pure-line varieties may result.

The ratio of GCA/SCA variances indicated a decreasing trend with advancement of filial generations in spite of the fact that it was always larger than 1 (Graph 1). In a self-pollinated crop as wheat, a decrease in heterozygosity would theoretically be expected with the advancement of generations and an increase in additive x additive type of interactions which should lead to an increase in GCA variances. However, this was not found in this study. Bhullar et al. (1979) found a trend for increase of the GCA/SCA ratio for grain yield, but a decrease in tillering capacity from the F_1 to F_3 generations. This situation could be due to a strong influence of environmental conditions on grain yield and SCA effects of the hybrids tested.

GCA effects - The comparison of GCA performances of most of the parents used in the diallels (Table 4) shows that GCA estimates over successive generations were rather consistent. This suggests that the crosses could be studied for combining ability in the F_2 (or F_3) instead of the F_1 generation when the objective is to breed pure line varieties. Similar findings have been reported by Bhullar et al. (1979) regarding several agronomic traits in wheat. This finding is of particular importance for wheat where it is difficult to obtain sufficient quantities of crossed seeds in the F_1 generation.

In the presence of considerable additive genetic variance (in this study, the GCA variances were consistently larger than SCA variances over successive generations) parents with the highest genetic potential for giving better segregants in segregating generations could be selected on the basis of GCA effects. On this basis, the parents Sava, Kavkaz and Bezostaia 1 with the highest positive GCA variances, proved to be the best combiners for the grain yield, while NS-732, Cajeme 71 and N. lot-1 were poor combiners(Table 4). Furthermore, the crossing of the most desirable segregants in the early generations would be useful for accumulation of additive genetic effects and creation of broader variability for grain yield.



Graph 1.

GCA/SCA ratio for grain yield in wheat over successive filial generations resulting from 8x8 diallel cross.

Table 4. General combining ability effects for grain yield in wheat over successive generations (1973-1978).

Cultivar	F_1	F_2	F_3	F_4	F_5	F_6
1. Sava	20.25	7.80	28.25	72.45	12.45	6.03
2. Bezostaia 1	30.35	8.50	3.55	38.85	40.35	27.22
3. Kavkaz	57.05	67.40	39.45	71.35	- 2.05	34.62
4. Libellula	-19.09	-25.00	5.75	27.45	- 5.05	12.83
5. Cajeme 71	-33.25	- 8.30	2.95	-48.05	-27.85	- 9.08
6. Siete Cerros	26.85	78.90	- 8.25	-68.05	- 4.65	-51.07
7. NS-732	-103.15	-78.50	- 7.45	-31.25	- 2.85	- 4.68
8. N. lot-1	20.99	-50.80	-64.25	-62.75	-10.35	-15.87
$S.E._{(gi)}$	8.53	14.51	9.56	11.58	16.44	12.27
$S.E._{(gi-gj)}$	12.89	21.93	14.46	17.51	24.86	18.55

The GCA effects of the parents were highly correlated with their mean values over successive generations with "r" ranging from 0.772 - 0.978 (Table 5). Thus, the higher the yield of a parent, the higher was its GCA and vice versa. If this is a general phenomenon, it might be possible to determine the breeding value of a parent by simply measuring its yield potential. However, since the parents of these diallels were not randomly selected, valid conclusions can only be drawn about the eight parental varieties used.

Table 5. Correlation between means of the parents used in the diallel cross and their GCA effects for grain yield in wheat over successive generations.

Generation	Correlation coefficient (r)
F_1	0.898
F_2	0.937
F_3	0.978
F_4	0.930
F_5	0.772
F_6	0.902

SCA effects - The estimates of the SCA effects (Table 6) generally were not consistent over successive generations and only three cross combinations showed positive SCA over all generations (Bezostaia 1 x N. lot-1, Kavkaz x Cajeme 71 and Cajeme 71 x Siete Cerros).

Table 6. Specific combining ability effects for grain yield in wheat over successive generations.

Cross combination	F_1	F_2	F_3	F_4	F_5	F_6
Sava x Bezostaia 1	16.79	- 3.3	18.59	-79.69	-129.19	-71.78
" x Kavkaz	-14.91	57.8	61.69	62.81	-139.79	24.82
" x Libellula	- 6.81	-46.8	95.39	-11.29	76.21	-17.38
" x Cajeme 71	-47.61	1.5	-19.81	15.21	136.01	8.52
" x S. Cerros	64.29	1.3	-40.61	-12.79	127.81	-56.48
" x NS-732	-54.71	-51.3	-49.41	23.41	-138.98	14.12
" x N. lot-1	7.19	54.0	- 5.61	-20.09	18.51	-65.98
Bezostaia 1 x Kavkaz	1.99	47.1	-33.61	-20.59	32.31	- 3.38
" x Libellula	-54.91	10.5	25.09	55.31	-1.69	21.42
" x Cajeme 71	13.29	-4.2	17.89	73.81	95.11	-19.68
" x S. Cerros	-32.81	23.6	36.09	93.81	43.91	-24.68
" x NS-732	-37.81	-54.0	3.29	-22.99	-69.89	48.92
" x N. lot-1	24.09	58.3	9.09	50.51	17.61	27.12
Kavkaz x Libellula	-28.61	-13.4	8.19	-34.19	64.71	-31.98
" x Cajeme 71	21.59	9.9	61.99	101.31	67.51	2.92
" x S. Cerros	30.49	34.7	-91.85	-45.69	32.31	17.92
" x NS-732	-65.51	74.1	-18.61	-15.49	25.51	-51.48
" x N. lot-1	116.39	-48.6	- 6.81	68.01	-33.99	2.72
Libellula x Cajeme 71	42.69	-25.7	-12.31	-77.79	-96.49	-22.28
" x S. Cerros	-7.41	-15.9	20.89	95.21	-124.69	16.72
" x NS-732	12.59	1.5	- 4.91	-69.59	35.51	-42.68
" x N. lot-1	-30.51	-16.2	32.89	67.91	43.01	4.52
Cajeme 71 x S. Cerros	22.79	93.4	49.69	62.71	18.11	21.62
" x NS-732	17.79	-57.2	-66.11	11.91	-118.69	- 0.78
" x N. lot-1	35.69	-16.9	-12.31	-122.59	- 48.19	-49.58
S. Cerros x NS-732	15.69	3.6	77.09	- 79.09	33.11	41.22
" x N. lot-1	-18.41	-27.1	6.89	- 69.59	- 80.39	-11.58
NS-732 x N. lot-1	- 7.41	37.3	66.09	21.62	66.81	9.02
S.E. (Sij)	26.15	44.47	29.32	35.50	50.40	37.62
S.E. (Sij-Skl)	36.47	62.03	40.89	49.52	70.31	52.48
S.E. (Sij-Sik)	38.68	65.79	43.38	52.52	74.57	55.66

Not a single cross combination showed negative SCA effects in all generations. Bhullar et al. (1979) reported similar findings regarding the consistency of SCA estimates from F_1 to F_3 generations for several agronomic traits, including grain yield in wheat.

It should be pointed out that the cross combinations with consistently positive SCA effects usually involved one high and one poor general combining parent (Bezostaia 1 x N. lot-1 or Kavkaz x Cajeme 71), but also two poor general combiners (Cajeme 71 x Siete Cerros). On the other hand, the cross combinations with negative SCA effects (Siete Cerros x N. lot-1, Cajeme 71 x N. lot-1, or Libellula x Cajeme 71) always involved two poor general combiners. Although it is not possible to draw a general conclusion from these results regarding the choice of parents for high SCA effects on the basis of their GCA performances, it might be suggested that parents with high positive GCA effects are most likely to give superior combinations in grain yield.

Finally, this investigation established that combining ability studies in the F_2 (or F_3) generation can provide reliable estimates of GCA effects of the parents used in diallels. The relative importance of SCA effects is not clear but may be more dependent on the set of parents chosen and environmental factors than the GCA.

References

Bhullar, G. S., K. S. Gills, and Alok Bhatia. Combining ability over successive generations in diallel crosses of bread wheat. Cereal Research Communications, Vol. 7, No. 3:207-213. 1979.

Bitzer, M. J. and S. H. Fu. Heterosis and combining ability in southern soft winter wheat. Crop Sci. 12:35-37. 1972.

Brown, C. M., R. O. Wiebel, and R. D. Seif. Heterosis and combining ability in common winter wheat. Crop Sci. 6:382-383. 1966.

Griffing, B. Concept of general and specific combining ability in relation to diallel crossing systems. Aust. J. Biol. Sci. 9: 463-493. 1956.

Gyawali, K. K., C. O. Qualset, and W. T. Yamazaki. Estimates of heterosis and combining ability in winter wheat. Crop Sci. 8: 3:322-324. 1968.

Ketata, H., E. L. Smith, L. H. Edwards and R. W. McNew. Detection of epistatic, additive, and dominance variation in winter wheat (Triticum aestivum 1. em Thell.). Crop Sci. V. 16:(1):1-4. 1976.

Kronstad, W. E. and W. H. Foote. General and specific combining ability estimates in winter wheat, Triticum aestivum Vill., Host. Crop Sci. 4:616-619. 1964.

Paroda, R. S. and A. B. Joshi. Genetic architecture of yield and components of yield in wheat. Indian J. Genet. Pl. Breed. 30: 298-314. 1970.

Virk, D. S. and H. S. Aulakh. The diallel cross analysis of grain yield and its components in bread wheat. Cereal Research Communications Vol. 33:4:305-315. 1975.

BREEDING OF INTENSIVE SHORT-STEMMED WHEAT VARIETIES IN BULGARIA

Todor Rachinsky
Bulgaria

Abstract

Short-stem and lodging resistant wheat varieties make up a larger and larger part of wheat production in Bulgaria. On the basis of these wheat varieties it is possible to guarantee the successive fulfillment of the national program for an increase of the average yields and the total grain production of bread wheats in Bulgaria.

The creation of the variety Russalka marked the beginning of the short-stem direction in breeding. The original and rich complex of valuable economical and biological qualities of Russalka served as a genetic basis for obtaining new improved varieties with genetic potential for productivity up to 100-120 q/ha. The short stem (70-75 cm), resistance to lodging, combination of earliness and good winterhardiness, high and universal resistance to brown rust and yellow rust, erectness of the green leaf system, large grains and increased protein content of the grain are the characteristics of the Russalka genotype that make it especially useful for hybridization.

The short-stem varieties Jubiley, Vega, Vratza, Rubin, Trakia, and Ogosta, developed later, already are widely produced. Yields of the variety Trakia reached 104.7 q/ha and that of Vega, 101.7 q/ha. The high yield potential in these varieties is combined with complex resistance to diseases, high qualities of grain and bread, and wide ecological plasticity.

A new program is now being conducted aimed at involving new genes in the short-stem biotypes to realize a complex resistance to diseases and increase 1000-grain weight and number of grains/ear. Some of the new forms with stem height of only 50-60 cm form up to 120-140 grains/ear. Others have increased protein content of over 18% and sedimentation values of over 80 ml.

The paper presents a review of the results obtained in breeding work aimed at developing short-stem wheat varieties in Bulgaria. Given are the methods of breeding and the qualities of the wheat varieties. Experimental data manifest the wide productive potentials of the newly-developed varieties that now are grown on a large scale in the country. The trend toward further intensification of wheat varieties is mentioned.

Institute for Wheat, Tolbukhin.

Introduction

Wheat breeding in Bulgaria dates back to the first decade of our century. Its development went through the stages of individual selection in local unimproved populations, through the first intervarietal cross in 1911 and the first hybrid variety No. 159 introduced into production in 1926. For a long time afterwards (until 1960-1962) of dominating importance were the comparatively extensive tall-stemmed varieties, typical representatives of which are variety No. 14, developed through selection in some local varieties, and No. 301 - a hybrid variety originating from the local wheat No. 16, the French variety Noe and the American line L-2010-A-4-1-1. The introduction of the Italian variety Mentana into hybridization in 1935 was of great importance for improving resistance to lodging and the earliness, but the varieties Ockerman and Jubileina developed in this period are, however, of a rather limited practical importance. (1, 2, 3, 11)

The basic wheat variety in the country for the period 1964-1972 has been Bezostaya 1. This variety was of great significance for the sharp increase of wheat yields in Bulgaria. Besides, it provided a basic imprint on breeding work as a whole, becoming the main component of hybridization and a donor of valuable characters of Bulgarian wheat varieties. The first results came on the basis of crosses between Bezostaya 1 and a large group of selected Italian and later Yugoslavian varieties. Bezostaya 1 turned out to be the desired component that could successfully combine high grain quality and winterhardiness with short stems, large ear and earliness of the Italian varieties. Particularly successful were the crosses between Bezostaya 1 and varieties Fiorello, Libelulla, Libero, Elija and Mara that gave the highly productive semi-dwarf varieties Levent, Dobrudja 1, Zlatia, Trapezitza, Rumelia, etc. Crosses between Bezostaya 1 and the Yugoslavian varieties NS-313 and NS-314 produced the semi-dwarf varieties Slavyanka and Toshevka, with high quality and significantly more resistance to diseases. The cross between Bezostaya 1 and Etoile de Choisie produced Ludogorka - a semi-dwarf variety of high quality. The cross Bezostaya x Yubileina 3 gave the most widely-spread variety in the country - Sadovo 1 (10).

Direct crosses of Bezostaya 1 gave, as a rule, varieties of medium height, the stem being 92-105 cm long. Possessing a higher productivity, good ecological plasticity, winter-hardiness and high quality of the grain, those varieties quickly made their way into production. Now the varieties Sadovo 1, Dobrudja 1 and Slavyanka represent the basis of the varietal structure in the country.

Programme for Developing Dwarf Varieties

Modern intensive wheat growing and the favourable climatic and soil conditions of our country make it imperative to introduce into production shorter-stemmed varieties, resistant to lodging, and having an increased productive ear potential and high and lasting resistance to diseases. Presently the average wheat yields for

the country reach 40 q/ha and in some districts they exceed 50-52 q/ha. The practical possibilities of obtaining 60-70 q/ha in production areas can be realized mainly by the use of more intensive short-stemmed varieties.

High yields in our country can be obtained, not only by introduced varieties, but by our own varieties that are well adapted to the local climatic conditions. Considering this necessity, we adopted a programme for the development of our own national bioecotype intensive dwarf wheat varieties.

Roussalka-The First Bulgarian Dwarf Wheat Variety.--The first cross was performed in 1960 (9). Detailed study of the available initial material directed our attention to the Italian variety S-13. The variety has a very short stem (50-55 cm), powerful leaf system, earliness combined with good winter-hardiness, a large, rough ear with well-developed awns and very large grains. Variety S-13 itself has an interesting distant ecologic geographical origin, being a hybrid between the Japanese variety Wase Nibay and the South/African variety Starling B.

For a second component we chose the nonidentified line BAN-54, similar to the Russian early varieties Skorospelka 2, Osetinskaya 2 and Mocinave. The line manifested winter habit, good winter-hardiness, earliness, high resistance to brown rust, a thin semi-dwarf stem and small grains of comparatively good quality.

The first Bulgarian dwarf variety Roussalka was created by the cross S-13 x BAN-54 in 1966. Roussalka manifests a rich complex of valuable biological and economical characters that define it not only as a new industrial type of wheat, but as an original genotype for breeding as well. The stem is 70-75 cm high and is resistant to lodging. Studies have shown that the short stem of Roussalka is controlled by 2 major recessive genes. Monosomic analysis of the character 'stem-height' of Roussalka proves that these 2 genes are located on chromosomes 2A and 2D (Table 1). The genes controlling the short stem of Roussalka are not allelic with those of many other varieties with dwarf and semi-dwarf stems. Crosses of Roussalka with such varieties gave lines with stems even shorter than both of the parents (Table 2). These possibilities seemed to be particularly useful for crosses with Yugoslavian, Russian and Mexican varieties. Genes controlling the short stem of Roussalka are distinguished for their large hereditary effect. A single back-cross with Roussalka is enough to divert the hybrid population sharply to the dwarf type of plants. With that scheme of crossing, about 80% of the individual plants in F_2 and F_3 have stem height equal to that of Roussalka. It was only natural that our further programme for developing intensive dwarf varieties should include Roussalka as the main donor of short stem.

Good earliness is the second most important quality of Roussalka. It forms ears and ripens 8-10 days earlier than Bezostaya 1. This earliness is combined with very good winter-hardiness - a combination that can rarely be achieved in breeding practice.

Table 1. F_2 monosomic analysis of stem height in variety Roussalka (excluding ear length).

Parents, combination	n	$\bar{X} + S\bar{x}$	VC %	±D	Significance
Roussalka	244	53.3±0.37	10.7	-18.3	
Chinese Spring	168	77.6±1.01	16.9	+ 6.0	
F_1 Chinese Spring x Roussalka	43	72.0±1.98	18.0	+ 0.4	
F_2 Chinese Spring x Roussalka	463	71.6±0.60	18.0	+ 0.0	
F_2 1A x Roussalka	269	69.6±0.71	16.7	- 2.0	+
2A x Roussalka	163	56.0±1.10	25.3	-15.6	+++
3A x Roussalka	343	63.2±0.70	20.9	- 8.4	+++
4A x Roussalka	197	69.8±1.08	21.7	- 1.8	
5A x Roussalka	380	66.9±0.82	23.8	- 4.7	++
6A x Roussalka	268	66.8±0.78	19.1	- 4.8	+++
7A x Roussalka	230	63.3±0.76	18.3	- 8.3	+++
1B x Roussalka	179	65.5±0.94	19.2	- 6.1	+++
2B x Roussalka	246	62.6±0.90	22.9	- 9.0	+++
3B x Roussalka	316	62.4±0.81	23.1	- 9.2	+++
4B x Roussalka	255	66.5±0.85	20.5	- 5.1	+++
5B x Roussalka	255	77.4±0.84	17.3	+ 5.8	+++
6B x Roussalka	401	76.1±0.59	15.6	+ 4.5	+++
7B x Roussalka	227	73.7±0.82	16.8	+ 2.1	+
1D x Roussalka	133	68.7±1.12	18.9	- 2.9	+
2D x Roussalka	211	57.7±0.95	24.0	-13.9	+++
3D x Roussalka	105	65.0±1.31	20.7	- 6.6	+++
4D x Roussalka	96	70.0±1.19	16.7	- 1.6	
5D x Roussalka	-	-	-	-	
6D x Roussalka	224	68.6±0.79	17.2	- 3.0	++
7D x Roussalka	223	68.7±0.82	18.3	- 2.9	++

Table 2. Stem height of new lines obtained by crossing Roussalka with other varieties.

Line No.	Combination	Stem height in cm		
		line	♀	♂
13-A	Roussalka x Tzervena Zvezda	55.3	72.3	83.6
2609-215	Roussalka x Rannaya 12	59.1	72.3	86.1
3006-44	Roussalka x Rumelia	68.2	72.3	90.6
561-4	Roussalka x Sonora 64	56.3	72.3	78.8
918-87	Roussalka x Skorospelka 35	58.0	72.3	96.4

Later this allowed the use of Roussalka as a "bridge" for transferring and integrating earliness with an even higher winter-hardiness. Roussalka's high resistance to diseases is one of the important components constituting the biological complex of valuable characters of the variety. It manifests a complete and general resistance to brown rust (Puccinia recondita) that has been preserved for 15

years, irrespective of the dynamics in race composition of that disease and the development of new aggressive biotypes in it. Roussalka is resistant to yellow rust too (Puccinia glumarum). Attacks of stem rust (Puccinia graminis) and powdery mildew (Erysiphe graminis) occur comparatively rarely.

Unlike many other dwarf varieties, Roussalka forms very large grains of compact endosperm, with 1000-grain weight often over 48-50 g. This character is very successfully transferred in hybridization. Some of the hybrid varieties from Roussalka have 1000-grain weight of over 60 g.

The valuable complex of characters allows higher sowing rates with Roussalka without danger of lodging. The leaves, having no rust, preserve their high assimilating ability. The process and the period of grain formation are fast and early. Thus, without being a variety with an exceptionally productive ear, Roussalka is in position to develop maximum yields, considerably higher than those of Bezostaya 1. Data from a 14-year trial with Roussalka at the Institute, Tolbukhin, are convincing enough to prove its advantages (Table 3).

Table 3. Comparison between yields of Roussalka and Bezostaya 1 for the separate years during the period of 1966-1979.

Year	Roussalka yield q/ha	Bezostaya 1 yield q/ha	%	±D q/ha
1966	50.1	53.4	93.7	- 3.3
1967	84.7	82.6	102.5	+ 2.1
1968	58.4	55.3	105.7	+ 3.1
1969	53.5	46.2	115.8	+ 7.3
1970	51.2	50.3	101.8	+ 0.9
1971	64.3	44.2	142.5	+20.1
1972	77.4	63.5	121.9	+13.9
1973	83.6	69.1	121.0	+14.5
1974	55.6	47.2	117.9	+ 8.4
1975	69.1	51.2	134.9	+17.9
1976	88.7	87.6	101.3	+ 1.1
1977	67.9	67.3	100.9	+ 0.6
1978	75.9	63.8	119.0	+12.1
1979	63.9	58.0	110.2	+ 5.9
Average	67.7	60.0	112.8	+ 7.7

The average yields of Roussalka for the period are 67.7 q/ha; that is, it outyielded Bezostaya 1 by 7.7 q/ha (12.8%). Grain yields of Roussalka reached over 80 q/ha in the 3 most favourable years 1967, 1973 and 1976. In the same period Roussalka's stem was 71.5 cm high, while the stem of Bezostaya 1 was 95.3 cm.

Including Bezostaya 1 in the breeding work for developing dwarf varieties.--An important task to be solved in our breeding programme was the development of dwarf varieties through hybridization and with participation of Bezostaya 1. Our aim was to enrich the genotype of the dwarf varieties with the particularly valuable qualities of Bezostaya 1 ie/winter-hardiness, good grain quality and stability of grain formation during time of ripening.

Particularly successful appeared to be the cross (Bezostaya 1 x Elija) x Roussalka that gave one of the most productive dwarf varieties, Trakia. Results given in Table 4 note the comparison of Trakia, Bezostaya 1 and the standard Sadovo 1 during the 5-year trials.

Table 4. Grain yield in q/ha obtained from variety Trakia in comparison with varieties Roussalka and Sadovo 1.

Year	Trakia	Roussalka	Sadovo 1	% of Roussalka	% of Sadovo 1
1975	81.1	69.1	60.1	117.4	134.9
1976	104.9	88.7	94.5	118.3	111.0
1977	83.2	67.9	68.3	122.5	121.8
1978	82.3	75.9	77.1	108.5	106.7
1979	73.9	63.9	57.6	115.7	128.3
Average	85.1	73.1	71.5	116.4	119.0
± D q/ha	-	+12.0	+13.6		

Having preserved the biomorphology of Roussalka, Trakia has at the same time significantly higher productive potential. At the Institute near Tolbukhin, Trakia has yielded for 5 years (1975-1979) an average of 85.1 q/ha, that is 12.0 q/ha (16.4%) more than Roussalka and 13.6 q/ha (19.0%) more than Sadovo 1. In 1976 Trakia yielded the maximum of 104.9 q/ha.

Besides Trakia, other dwarf varieties of productive importance have been developed. These are Vratza, Ogosta, Yubiley, Rubin and Bega. Data in Table 5 compare the productivity of these varieties and that of semi-dwarf ones. Data in Table 5 show the productivity of 13 Bulgarian wheat varieties grown on about 80% of the wheat areas in the country.

Stem-height of dwarf varieties varies between 67-77 cm and that of the semi-dwarf ones between 92-105 cm. Yields of dwarf varieties vary between 73.1 q/ha - 85.1 q/ha and that of the semi-dwarf ones between 65.6 q/ha - 73.0 q/ha.

All dwarf varieties are more productive than the semi-dwarf ones. The highest yielding semi-dwarf variety Dobroudja 1 has the same productivity as Roussalka. All dwarf varieties outyielded Roussalka, the ranges being from 3.5 q/ha for Vega to 12.0 q/ha for Trakia. All new Bulgarian varieties are more productive than Benzostaya 1, the increase of yield for dwarf varieties being 7.5 - 19.5 q/ha and 2.7 - 7.4 q/ha for the semi-dwarf ones.

Table 5. Mean 5-year results (1975-1979) from testing dwarf and semi-dwarf Bulgarian wheat varieties of the Institute near Tolbukhin.

Variety		Stem height cm	Grain yield q/ha	% of Bezostaya 1	± D of Bezostaya 1 q/ha
	Dwarf varieties				
Trakia	(Bezostaya 1 x Elia) x Roussalka	68.3	85.1	129.7	+ 19.5
Vratza	(NS-313 x Bezostaya 1) x Bezostaya 1 x Elia)	67.2	80.1	122.1	+ 14.5
Ogosta	(234 x S-13) x Bezostaya 1	70.1	79.6	121.3	+ 14.0
Yubiley	(Fleischman x Bezostaya 1) x Bezostaya 1	76.5	78.6	119.8	+ 13.0
Rubin	NS-175/2 x Bezostaya 1	77.0	77.1	117.5	+ 11.5
Vega	(301 x S-13) x Rannaya 12) x NS-314	69.2	76.6	116.8	+ 11.0
Roussalka	S-13 x BAN-54	69.7	73.1	111.4	+ 7.5
	Semi-dwarf varieties				
Dobrudja 1	Libellula x Bezostaya 1	92.5	73.0	111.3	+ 7.4
Levent	Bezostaya 1 x Fiorello	98.3	72.9	111.1	+ 7.3
Toshevka	NS-314 x Bezostaya 1	98.8	72.4	110.4	+ 6.8
Slavyanka	NS-313 x Bezostaya 1	97.3	71.8	109.5	+ 6.2
Sadovo 1	Ubileina III x Bezostaya 1	94.5	71.1	108.4	+ 5.5
Ludogorka	Bezostaya 1 x Etiole de Choisie	105.0	68.3	104.1	+ 2.7
Bezostaya 1		102.6	65.6	100.0	-

If compared with Bezostaya 1, the new dwarf varieties increased the productivity of wheat in Bulgaria by 20-30%. These varieties combined the valuable qualities of Bezostaya 1 with an even higher resistance to lodging, to brown rust and powdery mildew. This is of considerable importance to their high and stable productivity (Table 6).

When grown with high agrotechnics dwarf varieties yield over 70-80 q/ha, being at the same time practically completely resistant to lodging and brown rust and comparatively resistant to powdery mildew.

The participation of Bezostaya 1 in the development of the new varieties is of considerable importance for the high quality of grain and bread (Table 7). One of the greatest advantages of Bezostaya 1 as a parent component is its a ility to transfer the high quality of its grain to the hybrids. It is through Bezostaya 1 that the programme aimed at increasing the productivity and preserving and even improving grain and bread quality was most successfully realized. (4, 5, 6, 7, 8). Data in Table 7 show that,

Table 6. Resistance to lodging, brown rust and powdery mildew - average for 1975-1979.

Variety	Lodging %	Brown rust	Powdery mildew
	Dwarf varieties		
Trakia	2.4	0/R	15/MR
Vratza	3.5	0/R	10/R
Ogosta	10.8	0/R	45/MR
Yubiley	1.8	0/R	40/MR
Rubin	9.2	0/R	10/R
Vega	6.3	5/R	10/R
Roussalka	2.1	0/R	15/MR
	Semi-dwarf varieties		
Dobrudja 1	54.2	5/R	10/R
Levent	60.1	80/S	65/MS
Toshevka	51.6	15/R	25/MR
Slavyanka	36.3	10/R	25/MR
Sadovo 1	39.8	90/S	65/MS
Ludogorka	63.0	65/MS	30/MR
Bezostaya 1	74.9	60/MS	60/MS

of all the semi-dwarf varieties, Slavjanka is of better quality than Bezostaya 1, while Toshevka, Ludogorka and Dobroudja 1 are on the level of the standard. Of the dwarf varieties it is Yubiley that ranks closest to Bezostaya 1 with respect to quality. Trakia and Ogosta manifest a high quality of bread too, although their flour strength is inferior to that of Bezostaya 1.

New achievements in the intensification of the wheat plant.-- The new dwarf wheat varieties determined the characteristic features of a specific new ecotype excellently adapted to the conditions of Bulgaria. In the National variety testing, Trakia, Vratza, Vega and Ogosta come to the fore and outyield varieties introduced from other countries. What is more, Bulgarian dwarf varieties manifest a wide and well-expressed ecological plasticity: Roussalka ranked second in the 5th IWWPN in 1973, while Yubiley was on top in both the 9th and 10th IWWPN's in 1977 and 1978.

Henceforth, research work for improving wheat varieties was directed at increasing the productive potential of the ear, widening the complex resistance to diseases and searching for new possibilities of developing dwarf varieties of high protein content in the grain.

In the last few years a new variety appeared, notable for its exceptional productive potential. That is the variety Charodeika, obtained by crossing (Roussalka x Rannaya 12) x Zlatna Dolina. Charodeika combines all the best qualities of the Bulgarian dwarf varieties and the original qualities of the intensive Yugoslavian varieties. Due to its greater vegetative capacity and vitality

Table 7. Quality of grain and bread - harvest 1977.

Variety	1000 - kernel weight	Test weight kg/ha	Grain protein %	Wet gluten %	Bread volume cm^3	Relation H : D	Dough resistance min.	Valorimeter value
				Dwarf varieties				
Trakia	37.0	82.4	13.7	34.3	562	0.47	4.5	58
Vratza	36.9	82.5	13.8	30.3	520	0.39	4.4	56
Ogosta	37.6	82.0	14.2	32.2	547	0.44	5.2	58
Yubiley	38.7	83.2	14.8	33.4	527	0.50	8.2	74
Rubin	31.5	82.8	13.6	31.0	515	0.40	6.2	62
Vega	33.1	83.0	14.6	34.3	527	0.36	2.5	43
Roussalka	35.7	82.8	14.7	35.9	487	0.42	2.5	47
				Semi - dwarf varieties				
Dobrudja 1	37.2	82.7	14.3	33.1	565	0.48	8.3	71
Levent	37.3	81.1	13.9	37.9	533	0.40	5.2	62
Toshevka	33.6	81.9	15.0	33.0	557	0.41	9.2	76
Slavyanka	33.0	83.7	15.4	37.6	570	0.46	9.7	80
Sadovo 1	38.0	83.6	12.8	31.4	554	0.40	4.3	50
Ludogorka	29.2	82.9	14.6	35.3	547	0.44	8.0	73
Bezostaya 1	37.6	83.8	13.9	35.7	559	0.45	8.5	72

Charodeika forms ears much larger than all the others. At an optimum sowing density its spikelets form 4-5 well-filled grains and the whole ear numbers usually about 55-58 grains. Data in Fig. 1 reflect the progress and the stages in the intensification of Bulgarian dwarf wheat varieties in the last 10 years. Yields of Roussalka, Trakia and Charodeika in the years of 1977-1978 characterize best the stages of increasing the productive potential of Bulgarian dwarf wheat varieties. At the same time, they indicate the perfection of the genotype of Roussalka, first, on the level of Trakia and then, on the level of Charodeika. At an average yield of 65.3 q/ha for Bezostaya 1, Roussalka yields 71.9 q/ha, Trakia 82.8 q/ha, and the maximum is reached by Charodeika yielding 95.9 q/ha. It is notable that the high productivity level of Charoleika remains stable in both testing years, 98.4 q/ha in 1977 and 93.3 q/ha in 1978.

If the yield of Bezostaya 1 is taken as a base, the productivity of Roussalka will be 10.1% higher, of Trakia, 25.7% higher and that of Charodeika, 46.9% higher. While Roussalka yields 6.6 q/ha more than Bezostaya 1, the increase by Trakia is 16.9 q/ha and reaches the impressive maximum 30.6 q/ha with the variety Charodeika.

Increase of the productive potential in dwarf wheat varieties is now being realized on a wider genetic basis by utilizing more initial materials that introduce much better resistance to diseases and other unfavourable conditions into the newly-developed varieties. Some new intensive varieties are now being tested and multiplied. They appear to have a complex resistance to diseases, including stem rust, and preserved their leaf system fresh and green until ripening. Such qualities are inherent in the new intensive varieties No. 884-43, obtained by the cross (Super x Caucas) x 13-A; No. 933-118 originating from (Kapli x Supresa x Bezostaya 2) x 13-A; No. 908-A obtained by crossing (Roussalka x Caucas) x 200-699 x (TP-114/65A x 13-A). These varieties yield about 95-100 q/ha.

Conclusions

Wheat breeders in Bulgaria have carried out a programme aimed at developing intensive short-stemmed varieties successfully applied now in production. The first dwarf variety Roussalka possesses an original and exceptionally valuable complex of qualities. It became the forefather of other intensive varieties. Trakia and Charodeika, developed on the basis of the genotype of Roussalka, mark the climax of wheat productivity in Bulgaria.

An important stage in breeding directed toward dwarf varieties was the introduction of Bezostaya 1 in hybridization. Varieties, developed with the participation of Bezostaya 1 possess high grain and bread quality and wide ecological plasticity. Yubiley obtained by crossing (Fleischman x Bezostaya 1) x Bezostaya 1 is the variety of highest resistance to lodging and of the highest quality. In 1977 and 1978 Yubiley ranked first in the 9th and the 10th IWWPN.

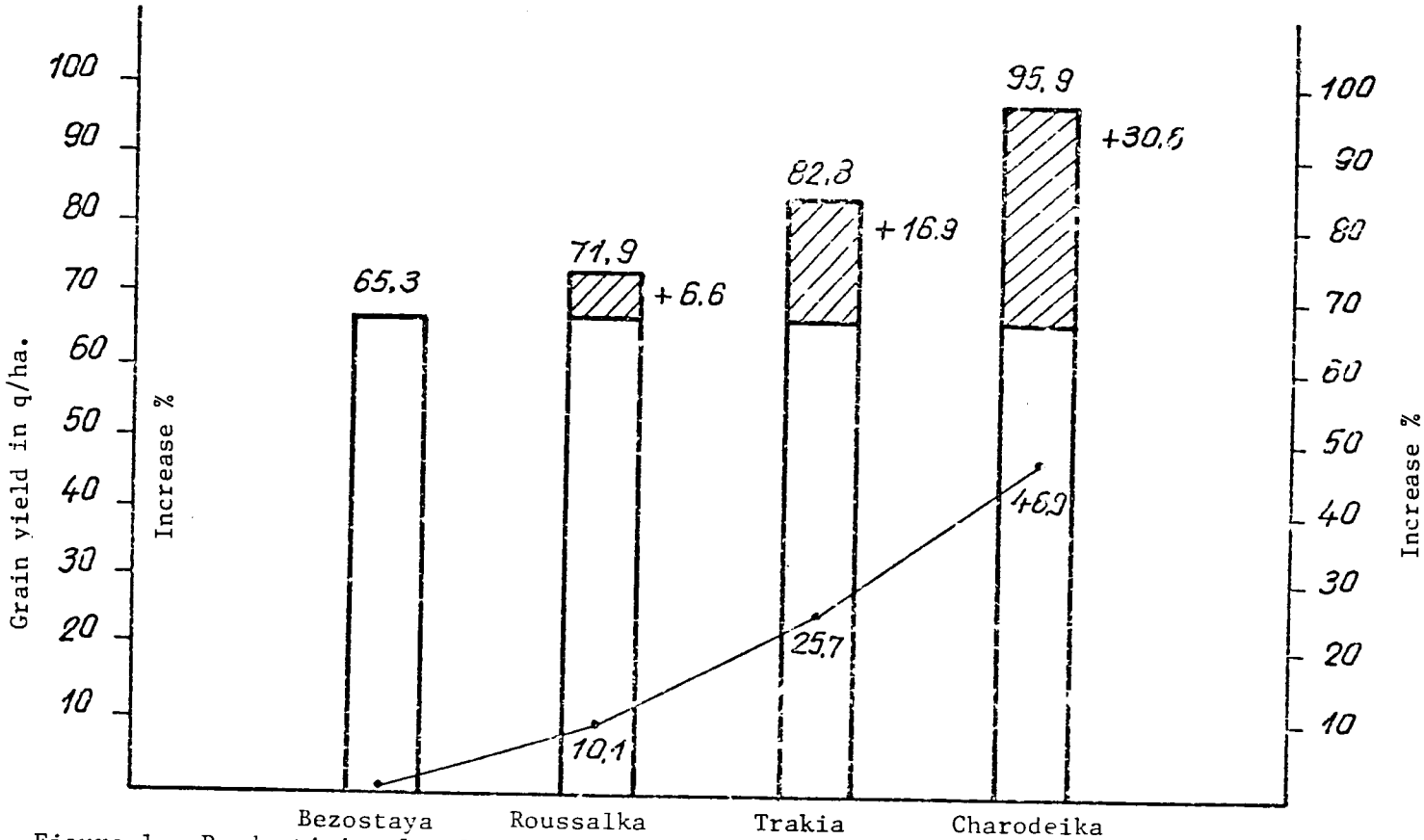


Figure 1. Productivity level in q/ha average for the 2-year period (1977-1978)

Bulgarian dwarf varieties have stems highly resistant to lodging, good winter-hardiness, complete and general resistance to brown rust, and, like Bezostaya 1, high grain quality. If compared to Bezostaya 1, the productivity of Roussalka is 10.1% higher and that of Trakia and Charodeika, respectively, 25.7 and 46.9% higher. Highest yields of Trakia, as much as 104.9 q/ha, were realized in 1976. Charodeika has yielded 98.4 q/ha in 1977 and 93.3 q/ha in 1978.

Intensive dwarf wheat varieties represent a good basis for a sharp increase of wheat yields in Bulgaria. In production conditions when grown over large areas, these varieties yield 60-70 q/ha, and the newest ones give hopes of reaching and even exceeding 80-85 q/ha.

References

1. Malkov, K. Sadovo, 5. 1902. No. 10-22, p. 179-183.
2. Popov, P. Yubileen sbornic na Sadovskata zemedelska opitna stantziya, Sofia, Zemizdat. 1958.
3. Rachinsky, T. Wheat Variety No. 301, Knezha, Nauchni dokladi, Yubileen sbornik 1960.
4. Rachinsky, T. Tsv. Rachinska - Genetika i selekziya. 1, No. 5, 1968.
5. Rachinsky, T., V. Gotsova - Genetika i selekzia. 3, No. 6, 1970.
6. Rachinsky, T., V. Gotsova, Tsv. Rachinska Rastenievadni nauki. 7, No. 2, 1970.
7. Rachinsky, T., V. Gotsova, Tsv. Rachinska. Genetika i selekzia. 5, No. 6. 1972.
8. Rachinsky, T., V. Gotsova, Tsv. Rachinska. Selekzia i agrotehnika na pshenizata i slanchogleda, Sbornik dokladi. 1977.
9. Rachinsky, T. Selekzia na intenzivni sortove pshenitza, Sofia, 1977.
10. Rachinsky, T., A. Zenov, D. Gotsov, D. Boyadjieva, D. Petrov. Selekzia na pshenitzata v Bulgaria, Sofia, 1978.
11. Cholakov, Zh. Rezultati ot podobritelnata rabota s mekata psheniza, 1942.

BREEDING PROCEDURE AND AGRONOMIC PERFORMANCE OF ADVANCED SEMIDWARF LINES SELECTED FROM THE CROSS ZLATNA DOLINA X KAVKAZ

Marijan Jost and Milica Jost
Yugoslavia

In the course of the research work on hybrid wheat carried out at Zagreb from 1972 to 1974, several promising wheat crosses for pure line selection were identified. One of the best cross combinations was 'Zlatna Dolina' x 'Kavkaz'. Respecting the opinion of Winhues (1968) that a strong heterotic effect should be generally appreciated as an indicator of good prospects of pure line selections, we continued the selection of superior homozygous segregants.

In this paper we should like to present the breeding strategy that developed during the research work and resulted in this proposal of the model for early generation selection for yield and bread making quality, and also the breeding procedure and performance of newly developed high-yielding semidwarf winter wheats.

Breeding strategy

In the past decade, several proposals were made of simple methods for improving the efficiency of selecting high-yielding genotypes in as early a generation after crossing as possible. Lupton and Whitehouse (1957) stated that selection in early generation is advantageous for characters that are highly heritable, not including yield. Recently, a number of new wheat varieties have been developed with considerable success by early generation selection, mostly in F_3. The variety Kavkaz , as well as a number of HRW wheats from the US Great Plains, are F_3 selections. It is generally accepted that selection for yield among F_2 plants is largely ineffective (Sneep 1977, Knott 1979). At the same time, however, new experimental designs were developed by means of which the efficiency of selection for yield in F_2 can be improved (Skorda 1973, Fasoulas 1973).

The main argument against early (F_2) generation selection for yield is the frequent lack of correlation between F_2 plant yield and F_3 plot yield in two successive years. This can mostly be explained by environmental variability such as soil heterogeneity and variations of climatic conditions during successive years of testing, or, in short, by genotype x environment interaction. According to Fasoulas (1973), one possible way of improving the efficiency of breeding for yield is to reduce environmental variability in the F_2 generation, and in this way increase heritability and efficiency of selection. He stated that a high level of soil fertility and the absence of competition are the conditions which permit phenotypic potentials to be fully expressed. He developed the honeycomb methods of selection: the ranking honey-

Faculty of Agricultural Science, University of Zagreb

comb design (RHD) - a replicated design for ranking parent plants according to their yielding ability, and the screening honeycomb design (SHD) - a nonreplicated design for screening a limitless number of genotypes, especially in F_2 generation.

In our opinion, the strongest support for early generation yield selection is the fact that the frequency of superior genotypes is much higher in F_2 than in F_4 or later generations. According to the calculations made by Shebesky and Evans (1973), if the parents differ by 25 important independent genes for yield, only one F_2 plant in 1330 retains the best 25 allels in either the homozygous or heterozygous condition. By delaying selection until F_4, only one plant in 1.8 million can be expected to contain all of the better allels. We completely agree with the question they posed: "Then why delay selection from F_2 to F_4?"

The next subject we should like to discuss is the proportion of the number and the size of crosses within a given total population size. In their recent papers, Yonezawa and Yamagata (1978) and Weber (1979), concluded that the number of crosses rather than the size of a cross, should be increased within a given total population size. It was even recommended to include also less promising crosses instead of enlarging the progenies of more promising ones. However, our practical breeding experience indicates that only large segregating populations can give us a chance to select superior genotypes. In this regard, it is our opinion that the most critical is the first segregating F_2 generation. Undetected or discarded superior F_2 genotypes would minimize the yielding and breeding potentials of F_3 and later generations of the cross. An adequate method for evaluating each F_2 plant would be the essential prerequisite for a successful selection of high-yielding homozygous lines in later generations. Despite the generally accepted opinion that single-plant performance under wide spacing conditions is not necessarily related to the population performance under close spacing, we find that the growth of spaced F_2 plants without competition by Fasoulas' SDH is the only suitable method to date. Another advantage of this method is its ability to produce a large number of seeds per plant, which allows the growing of adequately sized F_3 families, and makes it possible to carry out the first testing of some quality characters on F_2 plants.

As it is practically impossible to handle a large number of large F_2 populations and to conduct an effective selection of superior genotypes, it would be necessary to evaluate the yielding potential of each cross already in F_1. By discarding unpromising crosses, there would be a chance for enlarging F_2 populations of the few best crosses retained within the total scope of the breeding program. Here again the proper method would be the honeycomb design, this time the replicated SHD. As this method requires a relatively small number of hand-crossed F_1 seeds, there is a possibility of testing the seed in at least two contrasting environments. By testing at more than one location more reliable F_1 performance data can be obtained. Besides, yield stability being a genotypically controlled character, the use of two contrasting environments in later generation testing enables also the selection for grain

yield stability. In contrast to the usually applied breeding methodology of using several test sites, Jensen (1975) reported his "unorthodox methodology", one point of which being ... all breeding and testing operations at one location. His decision was based on the 10-year observation and the almost non-existing variety x location interaction in his geographic zone. After considering all the advantages of many test sites, and also one, but important, disadvantage - a rapid increase of the breeding program cost without a possibility of its extension, we have reached the conclusion that the proposed testing at two contrasting environments would be the most suitable and effective for the Yugoslav wheat growing area.

F_1 yield testing as a means of indicating the potentials of the cross, was also proposed by Knott and Kumar (1975). This approach was widely used in hybrid wheat breeding during the last decades in order to test the combining ability of parent varieties. There is also evidence (Nass, 1979) that the lines of crosses identified as high-yielding in F_1 had significatly higher mean yields in F_4 than those of crosses that were low-yielding in F_1. Thus, it is possible to identify promising crosses in F_1 provided an adequate testing method is applied.

For maintaining a reasonable, but effective, scope of the crossing program, a study of the characters of parent varieties is a necessity. Jensen (1975) considers that planning and hybridization are of critical importance to the creation of superior genotypes. The midparent value, F_1 yield and F_2 yield are recommended by Nass (1979) as a progressive set of tests for determining promising cross combinations.

In F_3 yield testing, we found to be most suitable the single small 3-row-plot (SSP) and the moving-mean analysis for plot selection. The moving-mean analysis was proposed by Townley-Smith et al. (1973). The authors reported that the moving-mean analysis is more effective in correcting for error than the use of a control every third plot as proposed by Shebeski (1967), or every fourth plot as proposed by Sneep (1977). In F_3 families (F_2 plant progeny), simple tests for milling and baking quality can be started (protein, Pelshenke, milling, microloaf baking). A single small F_3 plot would yield enough seed for:

a) replicated yield test for the evaluation of the yield potential and selection among families/lines, and;
b) seed purification and multiplication by SHD method, which also permits within family selection, and the best plant progeny propagation in the subsequent year.

Since 1972, following the early idea of Shebeski (1967), that the primary objective to increase the yield potential of wheat can only be met through the use of very large populations which are subjected to yield testing in early generations, we have been trying to develop our breeding strategy on the basis of five essential steps:

1) A study of potential parent varieties - to avoid making unpromising crosses.
2) A reasonable scope of the crossing program - too small or too large crossing programs give equally small chances of efficient selection of high-yielding genotypes.
3) Yield testing starting in F_1 - to determine the yield potential of the cross in two contrasting environments. Only the best, most promising crosses should be retained.
4) Growth of a large F_2 generation - by applying an adequate method and strong selection pressure. Select for highly heritable traits essential for high and stable yields (dwarfism, leaf-disease resistance, thousand kernel weight, etc.), and possibly for grain yield. The F_2 is the most critical generation.
5) Yield and quality tests in each subsequent generation - by means of adequate, simple but efficient methods and equipment available.

The proposal of this breeding strategy based on 50 crosses per year, is presented in the flow sheet (Fig.1). The selection pressure indicated can be modified and presents only an approximate value.

Breeding procedure and agronomic performance.

As previously mentioned, the cross Zlatna Dolina x Kavkaz manifested a high heterotic effect for grain yield per plant in F_1 and for grain yield per unit area in F_2. The two year averages for F_1 and F_2 were 140% and 113%,respectively (Fig. 2).

Of the three yield components, thousand kernel weight expressed the strongest heterotic effect in both generations (118% and 111%,respectively). Number of heads per plant in F_1 and per unit area in F_2, showed a lower heterotic effect, while there was no heterotic effect for the number of kernels per head. Jost et al. (1976) reported earlier that in Yugoslav growing conditions it is the character of the thousand kernel weight that is the most responsible for high grain yield of F_1 hybrids. Recently Smith (1979), and Schmidt and Ahad (1979) called attention to the value of yield components in breeding for grain yield increase. In their trials kernel weight and tiller number were positively correlated with grain yield, whereas kernel number per head was not. Thus, breeding for seed size offers a possibility of increasing the grain yield potential in wheat (Cammack and Smith, 1979), that is, thousand kernel weight is genetically the most reliable yield component in breeding work (Lelley, 1976; McNeal et al., 1978).

The good combining ability of the cultivar Kavkaz has been frequently reported (Lukijanenko and Timofeev, 1970; Fedin 1976; Mihaljev 1976; Orlyuk 1976; Popovic 1976). Besides, in the period of 1972 through 1975, both parent cultivars of the cross exhibited wide adaptability and grain yield superiority in the International Winter Wheat Performance Nursery (Stroike and Johnson, 1975).

Fig. 1

FLOW SHEET

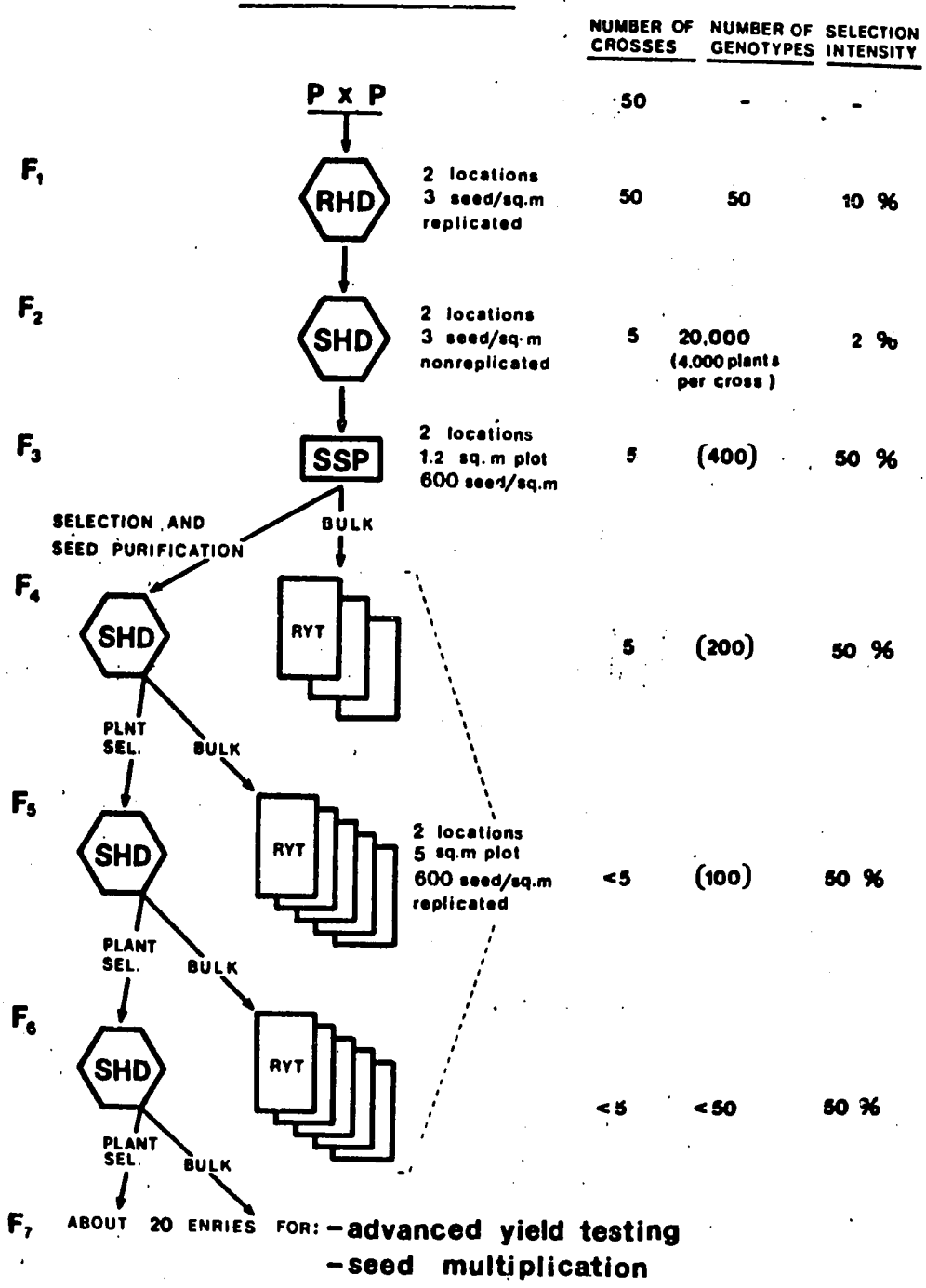
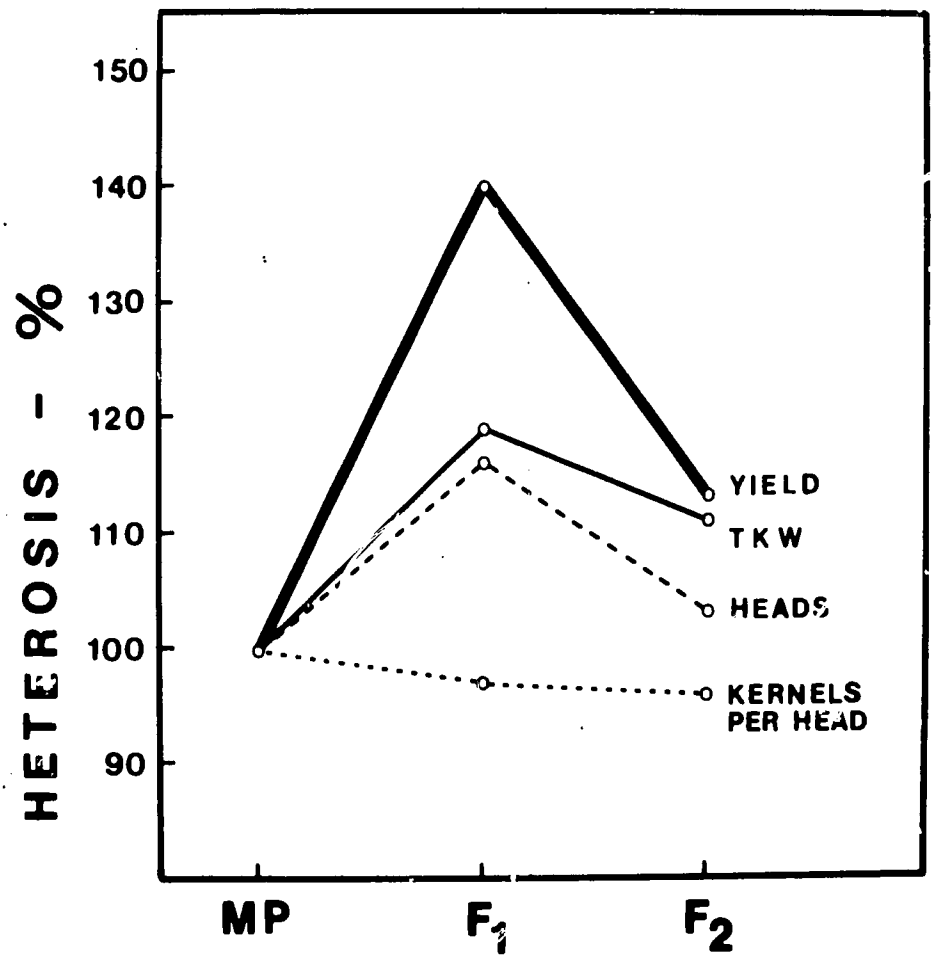


Fig. 2

HETEROSIS EFFECT FOR GRAIN YIELD AND THREE YIELD COMPONENTS OF CROSS **Zlatna Dolina x Kavkaz**. TWO YEAR AVERAGE:

F_1 in 1972 and 1973

F_2 in 1973 and 1974



Zlatna Dolina (pedigree: Libero/Dakota//Regent/3/Leonardo) is semidwarf, high-yielding, leaf disease tolerant, and in Yugoslavia, well adapted and a commercially grown cultivar. According to Lupton (1973), there is an important difference between the genes for dwarfism in Zlatna Dolina and those derived from Norin 10. Zlatna Dolina has two genes for stem rust resistance sr8 and sr17 (McVey and Roelfs, 1975).

In Yugoslavia, the cultivar Kavkaz (pedigree: Neuzucht/Bezostaya 4//Bezostaya 1) was grown in the early seventies, but is no longer grown. Because of its convential height and inclination to preharvest sprouting the variety was not able to compete with domestic, newly created, high-yielding, semidwarf wheats in spite of its many good characters such as:

a) Physiological properties: in a trial conducted by Borojevic (1973) the grain per leaf ratio was high (G/D), showing that with a relatively short leaf area duration (LAD) a high yield resulted. Kavkaz also has a higher net assimilation rate (NAR), higher dry matter production of the above ground part, and larger leaf area than the cultivar Zlatna Dolina (Stojanovic, 1978).

b) Disease resistance: Kavkaz is a spontaneous intergeneric translocation line, the SAT-arm of chromosome 1B having been replaced by a homoeologous segment of rye chromosome 1R (Mettin et al.,1973). It has been found that the rye chromosome 1R carries linked genetic factors conditioning resistance to powdery mildew, stripe rust, leaf rust and stem rust (Zeller 1973; Bartos et al., 1973; Robbelen and Sharp 1978). According to Fischbeck (1975), besides the translocation 1B/1R, with the appertaining genes, Kavkaz has an additional gene for stem rust resistance, Sr5, on chromsome 6D, and also a gene for leaf rust resistance, Lr3, on chromosome 6B.

c) Quality indices: Kavkaz is superior to Zlatna Dolina in all quality indices, especially in high grain protein content but not in alpha-amylase activity which is too high and effects inclination to preharvest sprouting and low maximum viscosity determined by the amylograph (Petric et al., 1975).

Both varieties show low sensitivity to the photoperiod (Martinic 1975) which is one of the prerequisites for good adaptation, and Kavkaz has fairly good winterhardiness. By collecting this information about parent varieties even after the cross had been made, that is, during the selection process, we were able to pay more attention to selecting for the characters with proven genetic background in the cross.

In spite of the known fact that dwarfism is correlated with low kernel weight (Zitelli and Mariani, 1973) we succeeded in selecting 142 semidwarf plants with high kernel weight out of the relatively large F_2 population of approximately 10,000 plants. Thus, the early selection for yield was based on two essential highly heritable parameters: semidwarf stature and high thousand kernel weight. After the preliminary yield test in F_4, thirty

semidwarf bulks were selected out of which 14 populations manifested superior agronomic characteristics in the subsequent investigation years, both in relation to the parent varieties and to the best commercial varieties of the region. It should be pointed out that all 14 populations originated from the same F_2 plant.

The 3-year averages of grain yield among the 14 selected populations ranged between 126 and 107% of the better parent Zlatna Colina (Fig. 3). Recently, there have been suggestions to express total protein yield per unit area rather than in terms of grain protein content. The protein yield per hectare, shown in this manner, was 46 to 28% higher in the 14 selected populations than in the variety Zlatna Dolina.

The general favourable characteristics of the 14 selected phenotypically uniform populations are the following: good tillering capactiy, lodging resistance, semidwarf stature, resistance to rusts (stripe, leaf and stem rusts), resistance to powdery mildew, good milling and baking properties (high protein content, high flour yield, high water absorption, high maltose content, good extensogram). An undesirable character is rather high alpha-amylase activity inherited from cultivar Kavkaz (Fig. 4).

In 1978, 660 F_7 plants were selected from the 14 populations for growing as plant-rows in 1979. After the harvest, analyses were made of 1000-kernel weight and grain protein content. Frequency distributions of the selected lines are shown for 1000-kernel weight (Fig. 5) and for grain protein content (Fig. 6). For both analysed traits rather wide variations were recorded, opening possibilities for further improvement of the characters by selection. It should be pointed out that in 1979 there was an extremely favourable environment for high grain protein development at Zagreb.

As there was some evidence that protein content appeared not to be correlated with quality (Fortini et al., 1975), we decided to use some additional relatively simple quality prediction tests such as the Zeleny sedimentation test and the Pelshenke test, modified by the procedure described by Villages and Borlaug (Welsh and Norman, 1972). It has been reported that the Pelshenke index shows a strong positive correlation with sedimentation value (Fortini et al., 1975) but not with protein content (Borghi et al., 1975; Welsh and Norman 1972), although there is also evidence of a significant and positive connection between the protein content and Pelshenke (Sohan Pal et al., 1977).

In our case, the analyses conducted on a smaller number of selected F_8 lines (n=35-130) did not show any correlation between 1000-kernel weight and the three wheat quality indices (protein, Zeleny and Pelshenke) nor between protein and Zeleny, and Pelshenke (Table 1.).

Fig. 3

Relative grain and protein yield of 14 selected semidwarf populations of cross ZLATNA DOLINA x KAVKAZ. Three year average, 1977 - 1979

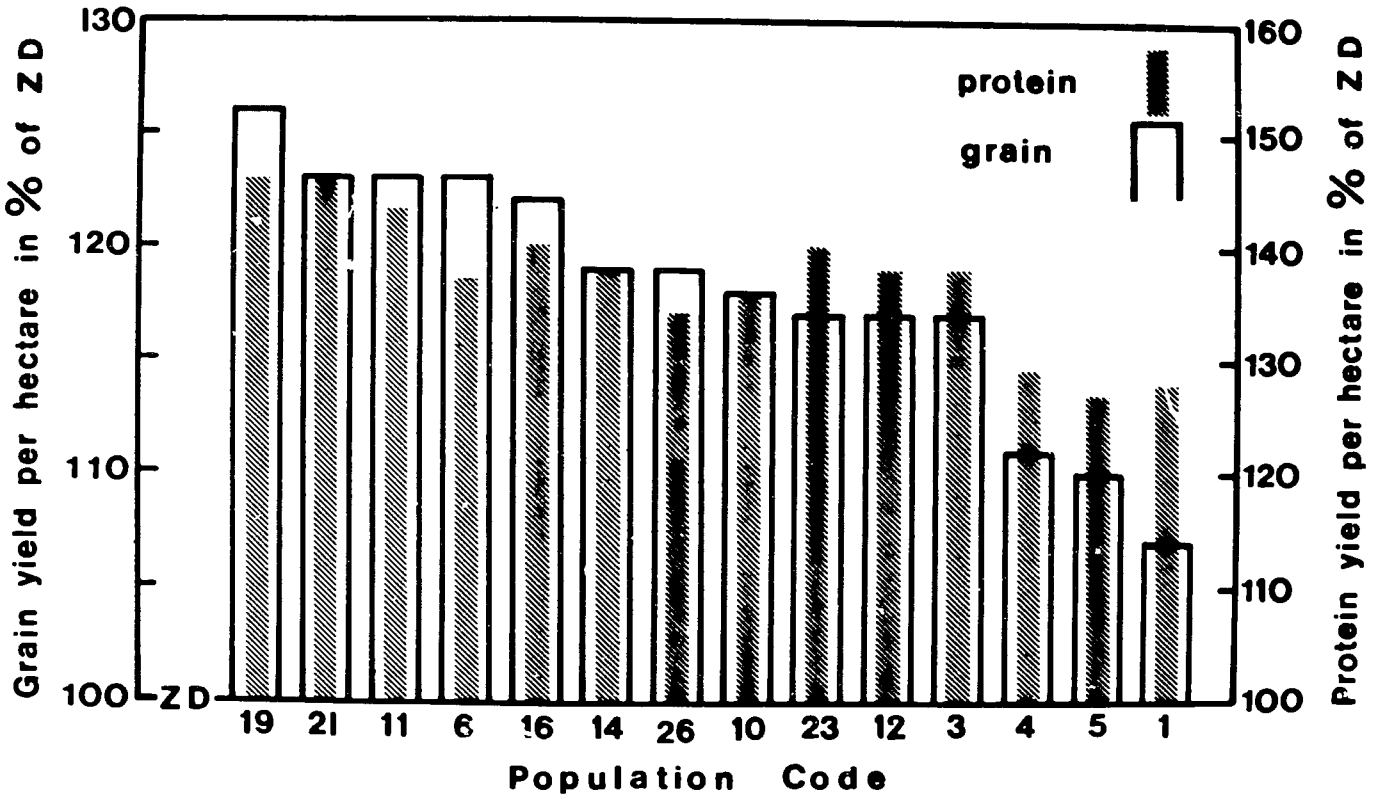


Fig. 4

Farinograms, extensograms, amylograms and some other quality indices of parent variety Zlatna Dolina, in comparison with one of the 14 selected populations, coded VG-23.

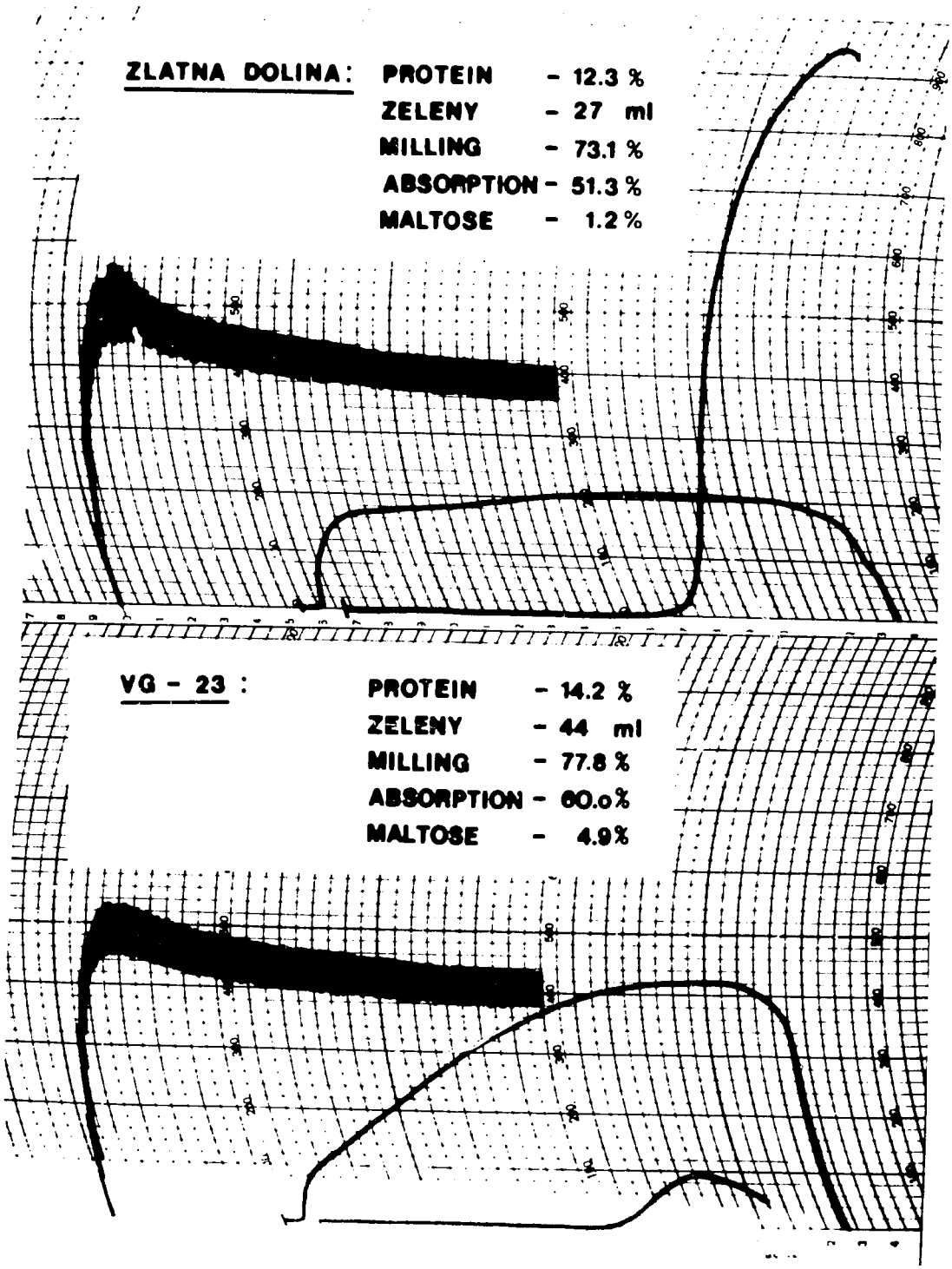


Fig. 5

Frequency distribution for thousand kernel weight of 658 F_7 selected F_8 lines of cross ZLATNA DOLINA x KAVKAZ

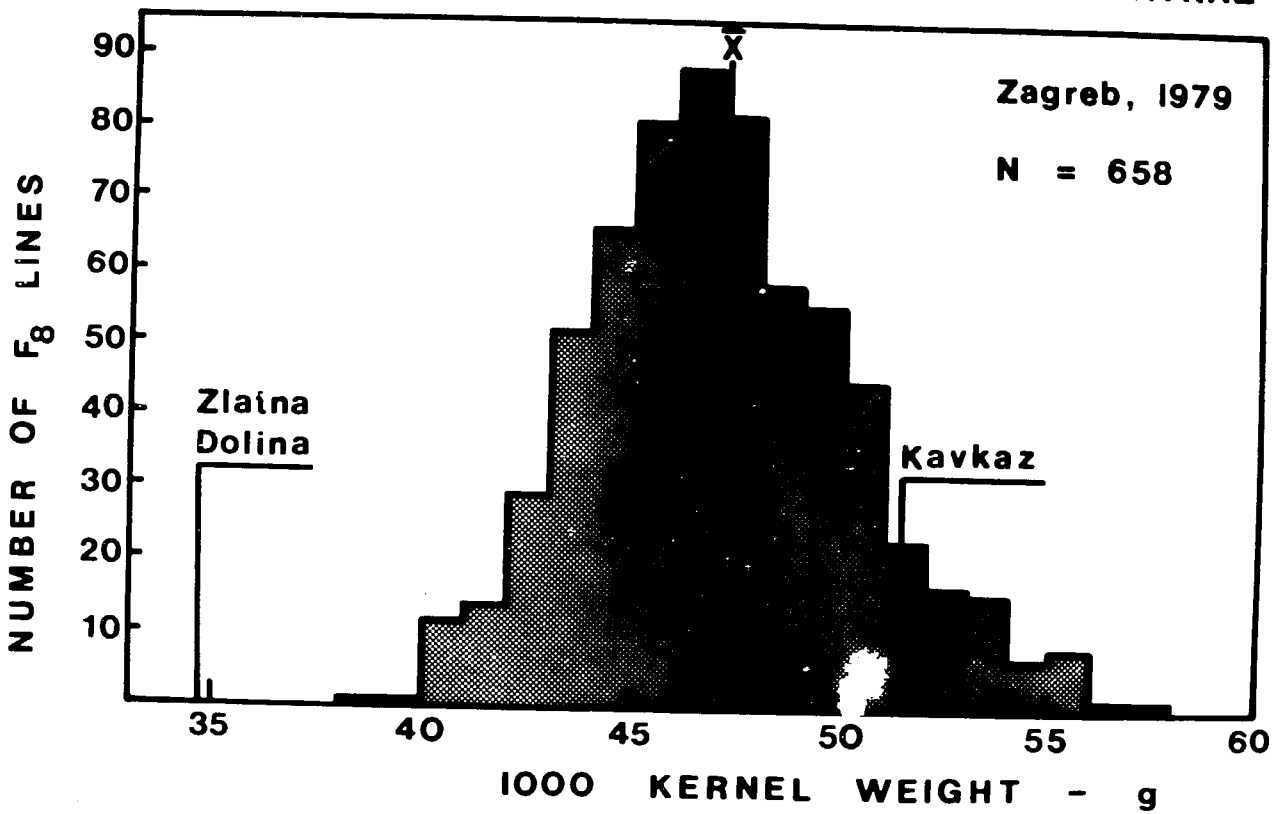


Fig. 6

Frequency distribution for grain protein content of 658 F_7-selected F_8 lines of cross ZLATNA DOLINA x KAVKAZ

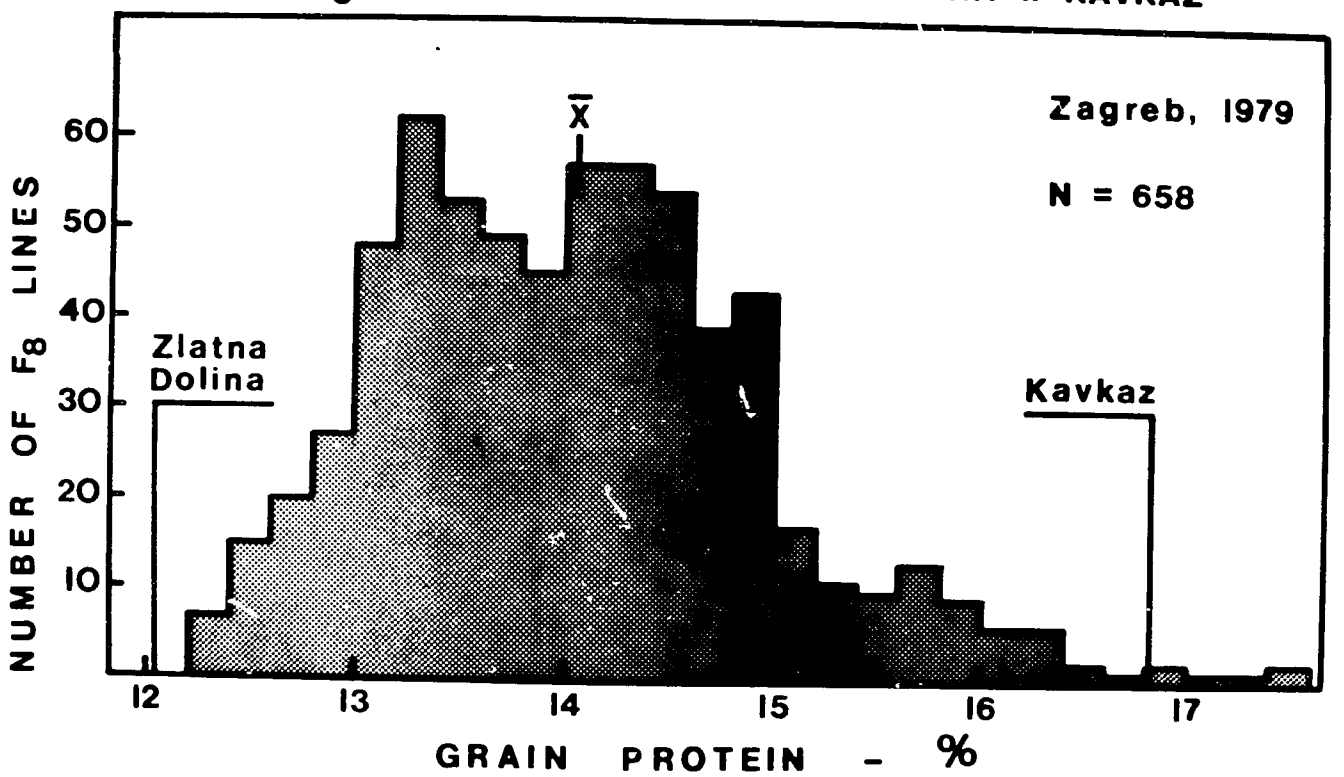


Table 1. Correlation coefficients/r/ for four quality indices of selected F_8 lines, Zagreb, 1979.

	T K W	G P C	Zeleny
G P C	-0.12		
Zeleny	0.24	0.34*	
Pelshenke	-0.05	0.09	0.33

The obtained results point to the possibility of further improvement of the characters relating to good bread making quality in the breeding material used without a negative effect on grain yield.

References

Bartos, P., J. Valkoun, J. Kosner and V. Slovencikova. 1973. Rust resistance of some European wheat cultivare derived from rye. Proc. 4th Int. Wheat Genet. Symp., Columbia, pp.145-146.

Borghi, B., A. Testoni, M. Cattaneo and M. Corbellini. 1975. Effects of genetic-environment interaction on different tests for bread making quality evaluation. Proc. 2nd IWWC, Zagreb, pp.423-434.

Borojevic, S. 1973. Canaopy structure of different wheat genotypes in relation to the yield of grains. Proc. 4th Int. Wheat Genet. Symp., Columbia, pp. 773-780.

Cammack, F.P. and E.L. Smith. 1979. Agronomic and quality characteristics of wheat lines selected for large seed size. Agron. Abstr., p.58.

Fasoulas, A. 1973. A new approach to breeding superior yielding varieties. Aristotelian Univ., Thessaloniki, Publ. No.3.

Fedin, M.A. 1976. Heterosis in wheat and its hereditary factors. Proc. 7th Congress of EUCARPIA, Budapest, pp.291-302.

Fischbeck, G. 1975. Genetics of disease resistance in European winter wheat breeding. Proc. 2nd IWWC, Zagreb, pp.449-460.

Fortini, S., G. Galterio, G. Zitelli and B. Borghi. 1975. Protein fractions in crosses involving lines differing in bread making quality and protein content. Proc. 2nd IWWC, Zagreb, pp.402-410.

Jensen, N.F. 1975. Breeding strategies for winter wheat improvement. Proc. 2nd IWWC, Zagreb, pp.31-45.

Jost. M., V. Hrust and J. Milohnic. 1976. Hybrid vigor in a twelve-parent diallel cross of common winter wheat. Agriculturae Conspectus Scientificus, 38(48):131-140.

Knott, D.R. and J. Kumar. 1975. Comparison of early generation yield testing and single seed descent procedure in wheat breeding. Crop. Sci. 15: 295-299.

Knott, D.R. 1979. Selection for yield in wheat breeding. Euphytica, 28:37-40.

Lelley, J. 1976. Wheat breeding - Theory and practice. Akademiai Kiado, Budapest.

Lukijanenko, P.P. i V.B. Timofeev. 1970. Izucenie geterozisa u mjagkoi ozimoi psenici. Vestnik s.-h. nauki 9:13-19.

Lupton, F.G.H. and R.N.H. Whitehouse. 1957. Studies on the breeding of self-pollinated cereals. Euphytica 6:169-184.

Lupton, F.G.H. 1973. The potential of semidwarf winter wheats. Proc. 2nd IWWC, Zagreb, pp.60-64.

Martinic, Z. 1975. Photoperiodism, vernalization and adaptation in common wheat. Proc. 2nd IWWC, Zagreb, pp.197-205.

McNeal. F.H., C.O. Qualset, D.E. Baldridge and V.R. Stewart. 1978. Selection for yield and yield components in wheat.Crop Sci. 18:795-799.

McVey, D.V. and A.P. Roelfs. 1975. Postulation of genes for stem rust resistance in the entries of the Fourth International Winter Wheat Performance Nursery. Crop Sci.15:335-340.

Mettin, D., W.D. Bluthner and G. Schlegel. 1973. Additional evidence on spontaneous 1B/1R wheat-rye substitutions and translocations. Proc. 4th Int. Wheat Genet.Symp., Columbia, pp. 179-189.

Mihaljev,I. 1976. Heterosis in grain yield and its components in common wheat. Agriculturae Conspectus Scientificus, Zagreb, 38(48):141-146.

Nass, H.G. 1979. Selecting superior spring wheat crosses in early generations. Euphytica 28:161-167.

Orlyuk, A.P. 1977. (Transgressive variation in winter wheat and its use in breeding). Pl. Br. Abstr. 11:10151.

Petric, D. 1975. Klasifikacija psenice. Novi Sad, Zagreb.

Popovic, A. 1976. Manifestation of heterosis in wheat hybrids. Agriculturae Conspectus Scientificus, Zagreb, 38(48):147-153.

Robelen, G. and E.L. Sharp. 1978. Mode of inheritance and application of genes conditioning resistance of yellow rust. Advances in Plant Breeding, Suppl. to Journal of Plant Breeding, Vol.9.

Schmidt. J.W. and A.A. Ahad, 1979. Yield components study in winter wheat. Agron. Abstr.,p.76.

Shebeski, L.H. 1967. Wheat and breeding. In:K.F. Nielsen(ed) Can. Centen. Wheat Symp., Saskatoon:242-272.

Shebeski, L.H. and L.E. Evans. 1973. Early-generation selection for widerange adaptability in the breeding program. Proc.4th Int. Wheat Genet. Symp., Columbia, pp.587-593.

Skorda, E.A. 1973. Increasing the efficiency of selection for F_2 plant yield by reducing environmental variability. Proc. 4th Int. Wheat Genet. Symp., Columbia, pp.595-600.

Smith, E.L. 1979. Analysis of yield components in a set of winter wheat genotypes. Agron. Abstr., p.78.

Sneep, J. 1977. Selection for yield in early generations of self-fertilizing crops. Euphytica 26:27-30.

Sohan Pal, J.P. Srivastava and P.L. Gautam. 1977. Study on genetic variability and correlation between protein content and Pelshenke value in wheat. Proc. 1st National Seminar on Genetics and Wheat Improvement, Ludhiana, pp.194-197.

Stojanovic, J. 1978. Prilog proucavanju fotosintetske produktivnosti nekih sorata psenice. Arhiv za poljopr. nauke, 115: 149-155.

Stroike, J.E. and V.A. Johnson. 1975. The international winter wheat performance nursery. Proc. 2nd IWWC, Zagreb, pp.501-510.

Townley-Smith, T.F, E.A. Hurd and D.S. McBean. 1973. Techniques of selection for yield in wheat. Proc. 4th Int. Wheat Genet. Symp., Columbia, pp.605-609.

Weber, W.E. 1979. Number and size of cross progenies from a constant total number of plants manageable in a breeding program. Euphytica 28:453-456.

Welsh, J.R. and R.M. Norman. 1972. Use of the modified Pelshenke test for early generation wheat quality screening. Crop Sci. 12:80-81.

Winhues, F. 1968. Long-term yield analyses of heterosis in wheat and barley. Variability of heterosis, fixation of heterosis. Euphytica 17, Supp. 1:49-62.

Yonezawa, K. and H. Yamagata. 1978. On the number and size of cross combinations in a breeding programme of self fertilizing crops. Euphytica 27:113-116.

Zeller, F.J. 1973. 1B/1R Wheat-rye chromosome substitutions and translocations. Proc. 4th Int. Wheat Genet. Symp., Columbia, pp.209-222.

Zitelli, G. and B.M. Mariani. 1973. Relationship between dwarfness (Norin 10) and agronomic traits in durum wheat used in breeding work. Proc. 4th Int. Wheat Genet. Symp., Columbia, pp.617-623.

WINTER X SPRING WHEAT BREEDING IN TURKEY

Kamil Yakar and Fahri Altay
Turkey

The increasing demand for wheat as a major food source in the world requires a continuing effort to obtain maximum production from existing resources. This includes both the development of superior cultivars and improved cultural practices. With the development of semi-dwarf, light insensitive wheat cultivars, new yield levels have been established for spring and winter type wheats as a result of intensive activities in the world. If further yield advances are to be achieved, additional genetic variation will be needed to reach the yield plateaus.

Winter and spring type wheats evolved under different selection pressures and they are genetically diverse types for further improvement. Historically, many outstanding wheat cultivars have been developed from such crosses for disease resistance or for other traits. By transferring the desirable traits from spring-type wheats to winter or vice versa it would appear that both types could be improved and yield plateaus removed.

Turkey is one of the major wheat-growing countries in the world. It made a breakthrough increase in wheat production in the last decade and has now become a wheat-exporting country. This success has been achieved by an increase in inputs, improved cultural practices, and high-yielding new varieties.

In Turkey, many years ago, the first winter x spring crosses were made to transfer certain traits from the spring types. Some wheat cultivars were developed from these crosses. For example, Ankara 093/44 which was developed in the 1950's is a selection from a cross between the loose smut-resistant spring wheat cultivar Mentana and drought-resistant winter wheat local cultivar 89/28. Other examples are Bolal 2973 (Cheyenne x Kenya - Mentana) and Kirac 66 (Florance x Yayla 305) which were developed in 1970.

Starting from 1970, more emphasis was put on making more crosses between winter and spring types with the beginning of a national wheat program to create more genetic variation by using different sources of germplasm, especially in Ankara, Eskisehir and Izmir.

Almost all main stations in Turkey are working with winter x spring material in their programs. As an example, in the 1977-78 and 1978-79 growing seasons Ankara tested a total of 1975 lines in its yield trials (Figure 1). Twenty percent of these lines were checks, 34% winter and 46% winter x spring. In 1978-79 growing season, Eskisehir worked with 675 lines in the yield trial stage including checks. Standard varieties, winter and winter x spring lines were 11, 42 and 47% of total entries, respectively.

Wheat Research and Training Center, Ankara

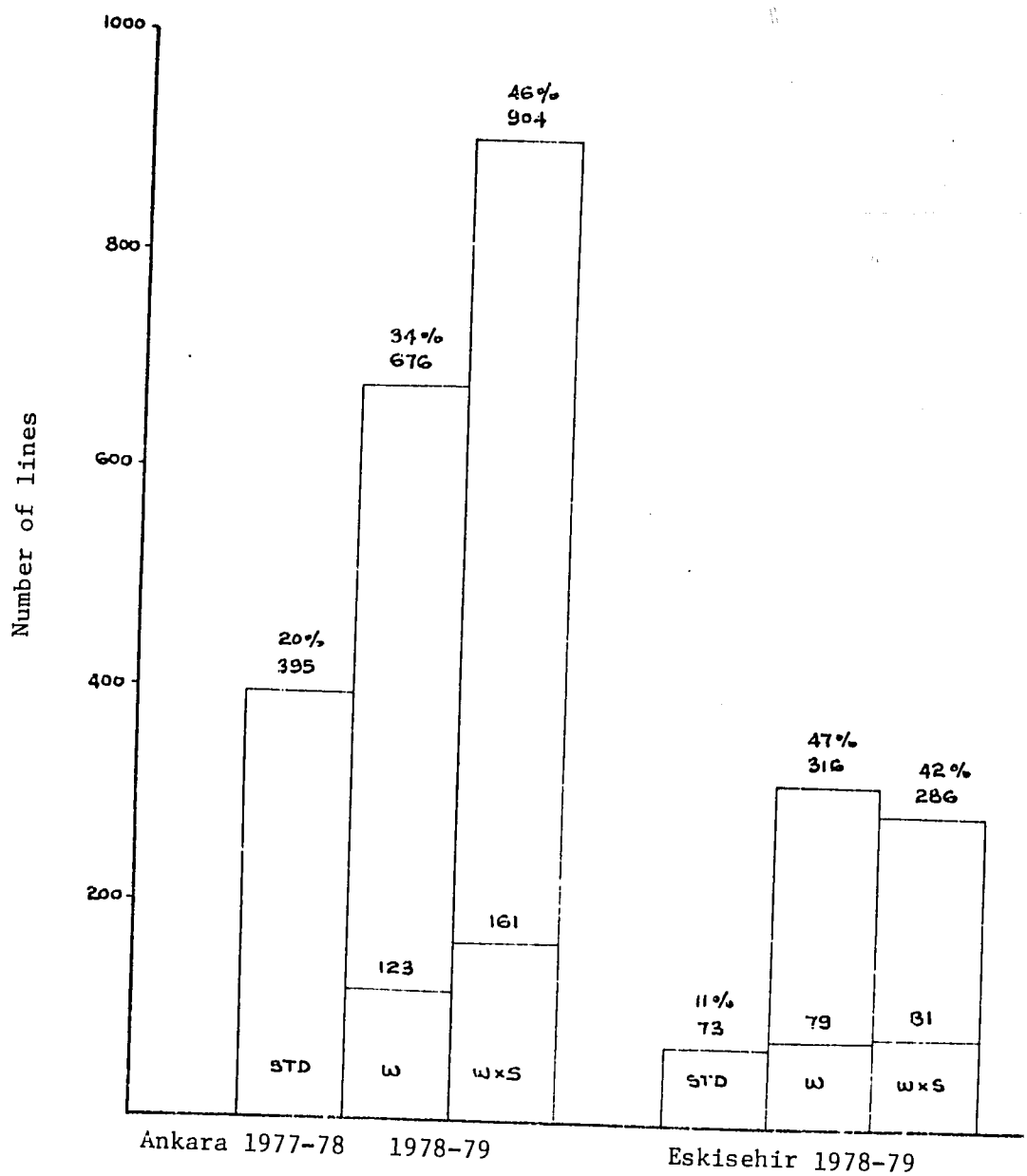


Figure 1. Number of standard varieties, winter and winter x spring lines sown in 1977-78 and 1978-79 crop seasons, Ankara, Eskisehir.

In these two years in Ankara, 123 winter and 161 winter x spring lines beat the best checks showing that 8% of the total were superior to the standard varieties. In Eskisehir, 79 winters and 81 winter x springs over-yielded the checks. The portion of winter x springs in the total was 11%. The purpose of winter x spring crosses is to broaden genetic variation, create new germplasm (disease resistant, high quality, winter-hardy, drought resistant, etc.) and improve new high-yielding varieties.

Broaden genetic variation-- To be successful in a breeding program, wide genetic variation is a must. Using different sources of material for crossing will create additional variation. A limited number of winter type materials for different traits will be increased by the use of spring material and this will help to make a large number of crosses and broaden the present variation.

Create new germplasm-- Most of the materials selected from the created variation through crossing are not expected to have variety potential. Most of these lines are being used as germplasm.

Disease resistance-- The major diseases in winter wheat growing areas in Turkey are the three rusts, common bunt and loose smut. One of the main objectives of the national program is to improve disease-resistant cultivars and also to create disease resistance sources to be utilized in the programs.

Evaluation of the 1978-79 TWWSN (Turkish Winter Wheat Screening Nursery) showed that 24 winter x spring lines were resistant to leaf rust (Table 1) and 17 to stem rust (Table 2) in Eskisehir. These lines resistant to the leaf and stem rusts were selected from Ankara, Eskisehir crosses and two of them from SWM (spring x winter Mexico). Another result obtained in TWWSN was the resistance to common bunt. Seven winter x spring lines were found resistant in Ankara, Eskisehir and Edirne in 1978-79 (Table 3). The winter x spring lines found resistant to the three rusts in greenhouse and field conditions in 1978-79 are listed in Table 4. The winter x spring lines resistant to loose smut and the three rusts in Ankara in 1978-79 are shown in Table 5.

Quality-- In the national program, the main quality evaluation starts in the yield trial stage. Complete quality analyses of every line in yield trials are performed. Sixty two lines in 1977-78 (Table 6) and 34 lines in 1978-79 (Table 7) were found to have high quality and 77 of these lines are winter x spring. In 1978-79, 144 lines out of 340 in the yield trial stage had more than 14% protein content of which 98 were winter x spring lines. Twenty lines out of the 98 had more than 15% protein content (Table 8). The protein content frequency distribution of 1976-77 and 1978-79 (Figure 2) showed significant progress in two years. The average value increased from 13.25 to 14.01% and the highest protein content value has reached to 18% from 16%.

Yield-- The yield data for two growing seasons at Ankara showed that the average yields obtained from standard varieties, winter

Table 1. WxS lines resistant to leaf rust, Eskisehir, 1978-79.

Hys"S"-7CxSk6888-Ja"S"/Nic	YA 6281-10A-0A
Pj62xYmh-Jar66/Kkz sel.7	YA 6471-8A-0A
Sol-B.ManxHys"S"-7C Rmy(Wa4767/ 391-56D-81-14-53x1015-6410)	YA 6577-4A-0A
T.Chin166-Ofm"S"/P26-67xM374-SX	YA 6568-6A-0A
Mxp66-BezxImp.Tmp	YA 7543-3A-0A
Sdy-Jupateco"S"	SWM 3903-1A-0A
V6707-Tanori71	SWM 4645-7A-0A
Timwin-Torim73	SWM 4728-5A-0A
Jup"S"xVg8994-Alma	SWM 5092-1A-0A
CchxHgn-Nai60	YA 3917-28A-3A-0A
Hys"S"-7CxKc66	YA 4883-14A-1A-0A
Cache/Bb-Nar67xCno"S"-7C	YA 2623-17A-1A-0A
Tmp64-TixMxp69	YA 2640-10A-1A-1A-0A
P253-6-C190-12	YE 1008-93-2-1E-0E
C182-4-C98-6	YE 1016-13-6-1-2E-0E
Au-Pj"S"x(White Grain)-Ykt406	YE 233-16E-1E-0E
Bez-Tevere	YE 5-8E-8E-1E-0E
P253-6-C190-12	YE 996-14E-1E-2E-1E-1E-0E
P253-6-C190-12	YE 996-14E-1E-2E-1E-2E-0E
P253-6-C190-12	YE 996-14E-2E-2E-2E-2E-0E
P253-6-C190-12	YE 996-14E-2E-2E-2E-3E-0E
C126-6-C190-12	YE 1008-95E-1E-2E-1E-1E-0E
C182-4-C98-6	YE 1016-13E-1E-1E-3E-2E-0E
C182-4-C98-6	YE 1016-13E-1E-1E-3E-2E-0E

Table 2. WxS lines resistant to stem rust, Eskisehir, 1978-79.

Y50E-Kal^{3}xKst/Qt254-Ravi66xMxp65	YA 6492-8A-0A
T-Chin(66xOfn"S")P26-67 M374-Sx	YA 6568-6A-0A
Hys-7C/Kaw^{5}xD528A-Pnc	YA 6877-5A-0A
Stepnaia 40/CC-IniaxBb	YA 7407-1A-0A
(Co672 884xCno"S"-Son64/C0652363)Agri	YA 7570-2A-0A
NB 64307xArt^2-7C	YA 7836-1A-0A
V 6707-Tanori 71	SWM 4645-7A-0A
Condor"S"xPj-Stacat	SWM 5128-6A-0A
Art^2-7CxB1	YA 4009-24A-2A-0A
Art^2-7CxB1	YA 4009-24A-1A-0A
Hys"S"-7CxImp Tmp	YA 4140-2A-6A-0A
Tmp64-TixMxp64	YA 2640-10A-1A-1A-0A
AgrixHys-7C	YA 268-1A-4A-4A-2A-0A
Aurora-Pj"S"x6B(W.grain)-Yektay 406	YE 233-10E-4E-0E
C122-6-C190-12	YE 1008-95E-1E-2E-1E-2E-0E
C182-4-C98-6	YE 1016-13E-1E-1E-3E-1E-0E
C182-4-C98-6	YE 1016-13E-1E-1E-3E-2E-0E

Table 3. WxS lines found resistant to common bunt in Ankara, Eskisehir and Edirne in 1978-79.

(Hys/Pi62-Chris"S"xNai60-Chris"S")Kc66	YA 1794-A-7A-0A
(Hys/Pi62-Chris"S"xNai60-Chris"S")Kc66	YA 1794-5A-8A-0A
(Hys/Pi62-Chris"S"xNai60-Chris"S")Kc66	YA 1794-5A-9A-0A
Kl pet-Rafx8156^2(R)/Bez-PI178383xOdin	SW072/H30-3A-0A
Atrtype^2-7CxAnza	SWO 220/1A-2A-0A
(Menk"S"-My48x4/14/Yy305)Bez-P101	YE 892-1A-1A-2A-0A
(P101-Yy305/Mq1-Tmx4/14)ND-P101xDrc	YE 921-2A-1A-6A-0A

Table 4. WxS lines found resistant to the three rusts in greenhouse and field tests in 1978-79.

Sdy-Jupateco"S"	SWM 3903-1A-0A
Hys"S"-7CxRjj12	YA 1 2-1A-2A-0A
Tmp 64-TixKxp69	YA 2640-10A-1A-1A-0A
P66-49-No.64	YE 728-6-1-1-2E-0E
Au-Pj"S"xGB(White grain)-093/44	YE 233-16E-1E-0E
Lom 11-Ykt 406	YE 21-12E-1E-3E-0E
Lom 11-Ykt 406	YE 21-12E-1E-4E-0E
Lom 11-Ykt 406	YE 21-16E-1E-1E-0E
Lom 11-Ykt 406	YE 21-16E-1E-2E-0E
C 182-4-C98-6	YE 1016-13E-1E-1E-3E-2E-0E

Table 5. WxS lines found resistant to loose smut, stripe, and leaf and stem rust in 1978-79.

LR64-IZ1813x4/11	YA 3813-16A-0A
LR64-IZ1813x4/11	YA 3813-21A-0A
093/44-Mxp66xLom10	YA 3824-21A-0A
Spk-SutxHys"S"-7C	YA 3923-7A-0A
Spk-SutxHys"S"-7C	YA 3923-8A-0A
Atr^2-7CxB1	YA 4009-13A-0A
Atr^2-7CxB1	YA 4009-24A-0A
Fs6-67xM374-SX	YA 4090-10A-0A
Au-Era	SWO 72/H319-2A-3A-0A
(Koy932/II21031-TprxC0652643) W22/Wa6984-Su92xBurt	YA 5557-6A-0A
(Spwt-GbxL/K58-NxF)Cno"S"-Pj62 Lut1	YA 5705-11A-0A
Tzpp-SK_ExLR64/Cnn	D 71368-2A-4A-2A-2A-0A
(Jd-JbxGb/Sdy)Kkz	D 71496-2A-1A-1A-2A-0A
Bez-Nar59	SWO 137-6A-7A-0A
Bez-Huamantla $Rojo^2$xMy54-N10B	YE 2-8-2-0E
Ykt406-No.57/Bez-P101xK1 luc	YE 1289-20-5-1-03
B1-No.64/Fortunato-C113170xCmn.	YE 1298-11-2-1-0E
P218-165-StrampellixNo.64	YE 1326-1-1-1-0E
P221-335-7907xAu	Ye 1340-5-2-1-0E
P221-335-7907xAu	YE 1340-5-2-2-0E
P225-126-7947xKkz	YE 1346-14-2-1-0E
P231-112-NS756xKkz	YE 1363-9-1-1-0E
P231-112-NS756xKkz	Ye 1363-9-1-3-0E
P233-104-7943xNo.64	YE 1365-1-1-1-0E
P233-104-7943xNo.64	YE 1365-2-1-2-0E
P233-115-NS756xAu	YE 1368-5-2-1-0E
P66-49-No.64	YE 728-6-1-1-2E-0E
P235-5-C98-7	YE 994-25-1-2-1E-0E
P253-6-C190-12	YE 996-2-2-3-1E-0E
P253-6-C190-12	YE 996-24-5-1-1E-0E
P253-6-C190-12	YE 996-25-2-1-1E-0E
P253-6-C190-12	YE 996-28-2-3-1E-0E
P126-6-C190-12	YE 1008-93-2-1-1E-0E
P126-6-C190-12	YE 1008-93-2-1-3E-0E
P126-6-C190-12	YE 1008-93-2-2-1E-0E
C126-15-Cofn"S"/N10B-P14xP101	YE 1013-7-3-4-2E-0E
C126-15-Cofn"S"/N10B-P14xP101	YE 1013-28-1-4-2E-0E
V64064-1-23-P220-83xStrampelli	YE 1041-9-2-1-6E-0E
V64058-1x093/44-P46-16	YE 335-10-1-2-5-2E-0E
Lom11-Ykt406	YE 21-1-2E-0E
Lom11-Ykt406	YE 21-1-4E-0E
Lom11-Ykt406	YE 21-1-5E-0E
Lom11-Ykt406	YE 21-1-8E-0E
Nai60-HnVII	C 437-4E-2E-3E-3E-0E
7C-6720xMcD-Fx	OWW 71416-1W4
Nad63-Sut	CO 701247
P253-6-C190-12	YE 996-37E-1E-0E

Table 6. WxS lines with good quality in 1977-78.

Austr-Nad63xKirik	YA 1792-2A-2A-0A
Sut/Qv-TmxMql-Oro	NB 68435
Mxp66-Bez	M 70205-11A-5A-0A
NadxTmp-CI12406/093/44	YA 2487
Nad63xTmp-CI 12406	CO 723623
II21031-C0652142xMara-Sut	CO 701733
KM 1718-7C	SY69-5Y-2Y-0Y
C.Vil (36896-Cj54xY54/5840) MPI5 Mxp65 Sut	YA 1930-6A-4A-0A
(CD-P101xDrc)^2/63-19 450$_E$-Kal	YA 2128-2A-1A-0A
Kl.Pet-Rafx8156^2/Bez-P1178383xOdin	SWO 72/H30-3A-1A-0A
Au-B.Man	SWO 72/H322-3A-1A-0A
V64064-P242-160(FnxK58-N/Tmp)	YE 1043-10A-15A-1A-0A
R 1812-Yr70	SE 345-12A-1A-1A-0A
Kkz-Pato(B)	SE 373-2A-4A-1A-0A
Kkz-Pato(B)	SE 373-3A-3A-2A-0A
Kkz-Pato(B)	SE 373-6A-1A-4A-0A
BhrxMy48-My54/Bez	D 70097-5A-1A-1A-1A-0A
BhrxMy48-My54/Bez	D 70097-9A-7A-1A-1A-0A
II 18889-TprxC0652643	CO 724101
Kc66-Bez/II50-18-P101xII50-18-Vg Dwf	YE 998-19A-1A-5A-0A
Lcr-Son64xCtk	7120-2-0A
Lut 7-Bb	SE 335-13A-3A-6A-0A
M 374-5x	

Table 7. WxS lines with good quality in 1978-79.

NadxTmp-CI12406	
II21183-C0652643xMara-Sut	CO 701916
V64064-P242-160(FnxK58-N/Tmp)	YE 1043-16A-1A-6A-0A
Mex71045-C0652643xLcr	CO 7312802-5A-5A-0A
Nad-C0652643xGuide/Baca	CO 7312944-6A-8A-0A
Soty-SutxLcr/Baca	CO 73147-6A-1A-0A
Jar"S"xTpr-C0652643	CO 721629
Nad63xTmp-CI12406	CO 723623
Mxp65-Bez	M 70205-11A-2A-0A
Mxp66-Bez	M 69134-41A-1A-0A
Mxp65-Bez	M 69135-34A-1A-1A-0A
Kc66-Bez/II50-18-P101xII50-18-Vg Dwf	YE 998-19A-1A-5A-0A
Kc66-Bez/II50-18-P101xII50-18-Vg Dwf	YE 998-22A-1A-1A-0A
Nad-C0652643xGuide/Lc	CO 7311284-5A-3A-0A
Nad-C0652643xGuide/Lc	CO 7311284-8A-1A-0A
Nad-C0652643xGuide/Ctk	CO 7315256-1A-1A-2A-0A
(Pi62-654xTzpp/Nar)Tpr Wrr Ctk	CO 7315765-6A-2A-0A
(Pi62-Y54xTzpp/Nar)Tpr Wrr Ctk	CO 7315765-6A-4A-0A
Mex71045-C0652643xLcr/Ctk	CO 7317294-3A-4A-0A
II18888-C0652142xMara-Sut/Ctk	CO 7318298-2A-2A-0A
Pj62-Lut32	M 70255-11A-3A-1A-3A-0A
V64059-2-3-P241-76xKkz	YE 1039-10E-2E-0E
Hys"S"-N066xMld/Kc66	YA 3679-1A-3A-0A
21183-C0652643xLcr-KS62136	CO7725082

Table 8. WxS lines containing more than 15% seed protein in 1978-79.

Mxp65-Bez	M 70205-11A-2A-0A
Mxp66-Bez	M 69134-41A-1A-0A
Mxp65-Bez	M 70205-11A-5A-0A
II21185-C0652363xMara-Sut	CO 701916
Pi"S"-LR^{2}xCC-Crim/Kc66	YE 1917-2A-12A-0A
Kc66-Bez/II50-18-P101xII50-18-Vg Dwf	YE 998-19A-1A-5A-0A
Kc66-Bez/II50-18-P101xII50-18-Vg Dwf	YE 998-22A-1A-1A-0A
Mex71045-C0652642xLcr/Ctk	CO 7317294-3A-4A-0A
Pj62-Au	M 70255-21A-1A-2A-1A-0A
Drc-SXxSoty/B1	YA 3848-9A-0A
Atr^2-7CxB1	YA 4009-13A-0A
Hys"S"-7Cx1593/51	YA 4148-9A-0A
Kanred-FunoxII9933-3B-1Y-1B-1Y	YA 4302-5A-0A
Bb-7Cx093/44	YA 2485-20A-1A-0A
AgrixNad63-C0652643	YA 2529-6A-1A-0A
Hys-N066xM1d/Kc66	YA 3679-1A-2A-0A
AgrixNad63-C0652643	YA 2524-10A-3A-0A
(Cj54-36896xGb56^2/Yalta)Mxp65 Bez	YA 2553-15A-3A-0A
Hys-N066xM1d/Kc66	YA 3679-1A-3A-0A
Ji-Hys	SWO 72/H141-2A-5A-0A

and winter x spring lines were 267,272 and 276 kg/da, respectively (Figure 3). The average yield of the best checks in all yield trials was 312 kg/da. The yield level of the winter lines which were higher than the best checks was 340 and the winter x spring material was 342 kg/da. This indicated that the yield level of winter lines was 9% and winter x spring material was 10% higher than the best checks.

The yield results obtained from Eskisehir (Figure 4) showed that the average yield of the standards was 291, the winters' was 283 and the winter x springs' was 288 kg/da. The highest checks reached a 324 kg/da yield average while for the winters it was 361 and for the winter x springs 337. The yields of winter x spring were 4% and the winters were 11% higher than the best check's average.

With the help of new wide genetic variation, substantial progress in yield in the winter wheat program was achieved. As an example, the average yield of lines obtained in the 1972-73 crop season in the TWWSN at Erzurum was 180 kg/da. The yield average of TWWSN in 1978-79 at the same site was 300 kg/da (Figure 5).

Winterhardiness-- Insufficient winterhardiness is a factor which influences fall seeded small grains in the northern parts of Europe, Asia and the United States. The cultivars developed for the winter wheat zone in Turkey need to have a good level of winterhardiness. Evaluation is done on the basis of leaf damage using a 0-9 scale.

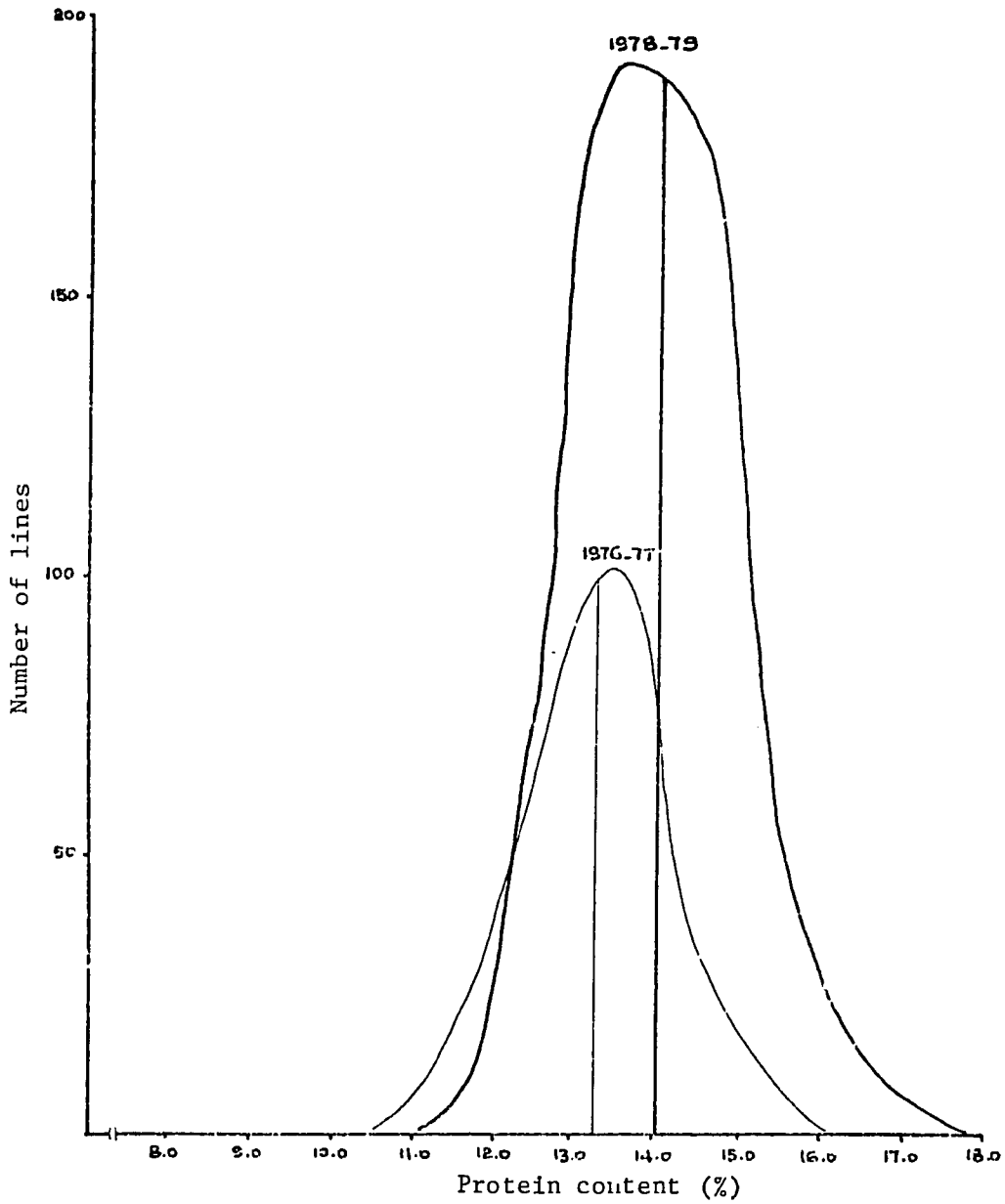


Figure 2. Protein content distributions of the lines in yield trials in 1976-77 and 1978-79 crop seasons, Ankara.

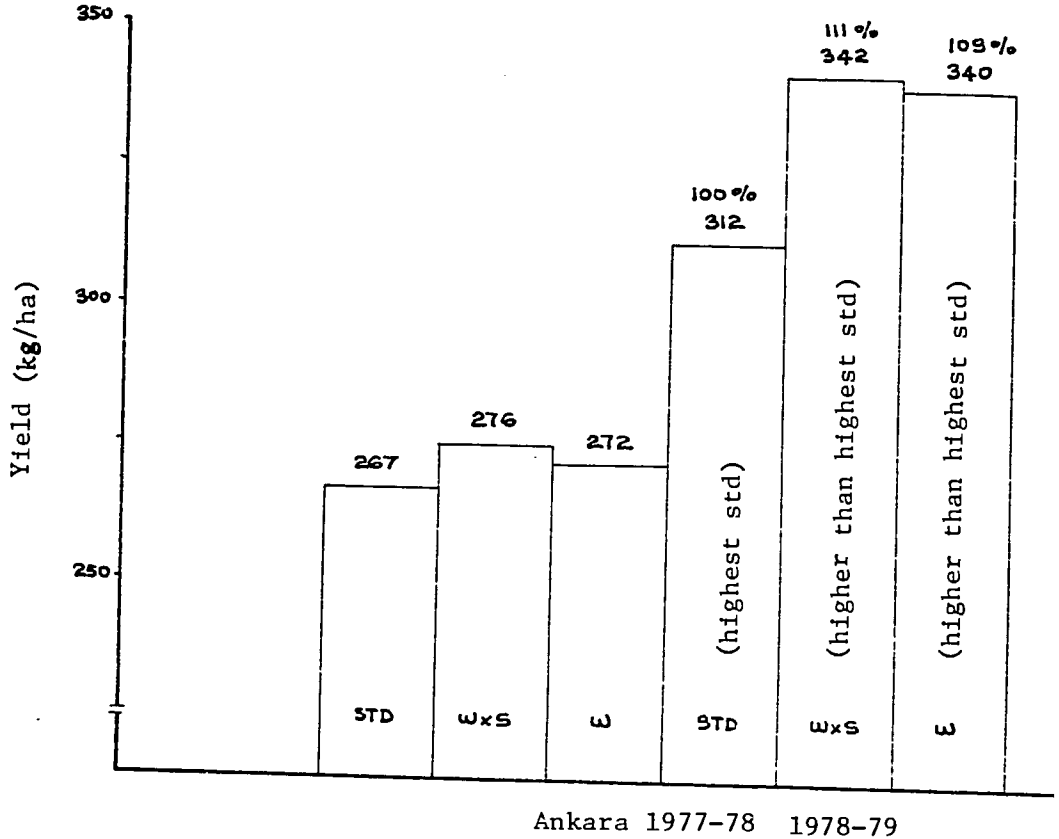


Figure 3. Average yield of standard varieties, winter and winter x spring lines, Ankara, 1977-79.

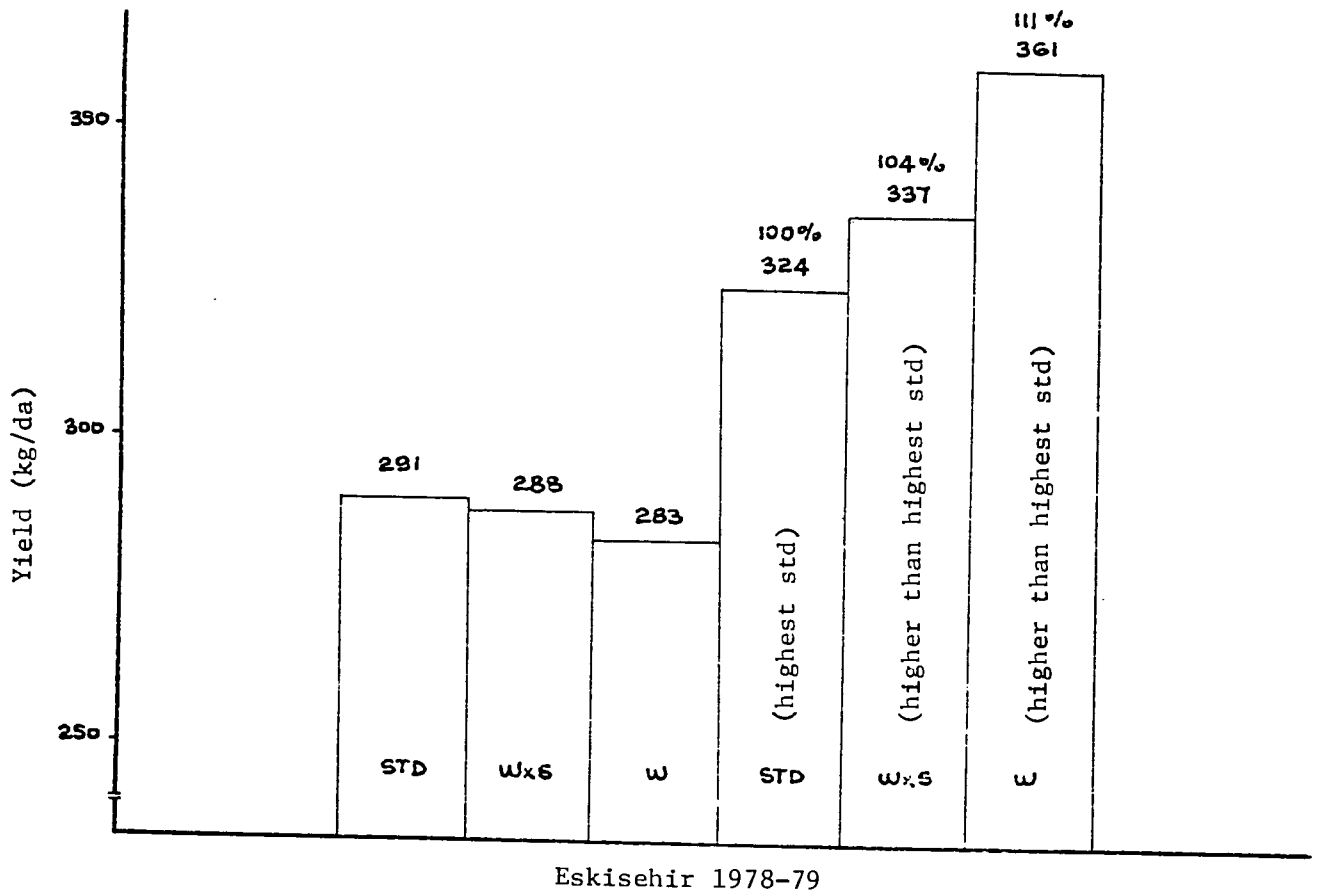


Figure 4. Average yield of standard varieties, winter and winter x spring lines, Eskisehir, 1978-79.

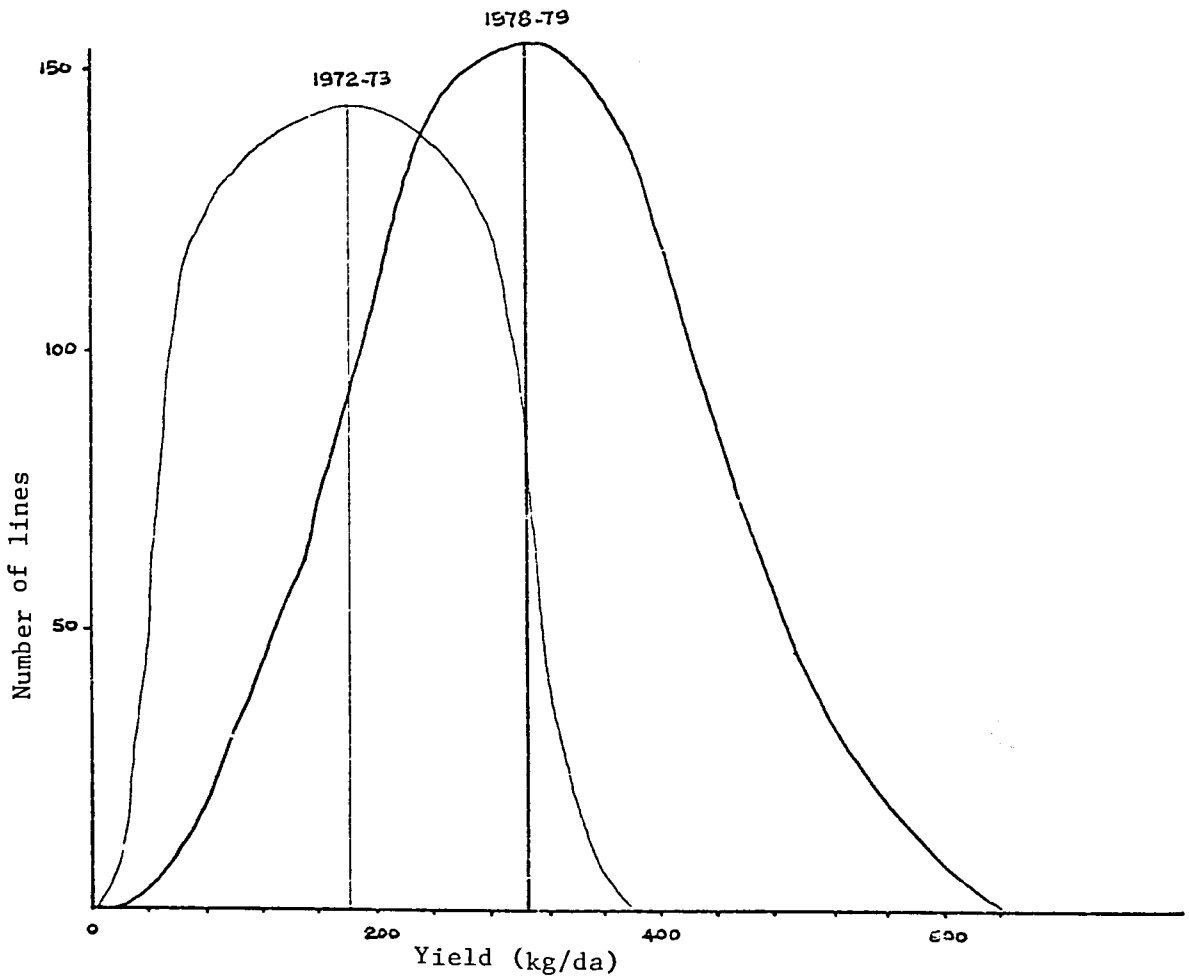


Figure 5. Yield distributions of the lines in TWWSN in 1972-73 and 1978-79 crop season, Erzurum.

The average leaf damage ratings obtained in standard varieties, winter and winter x spring lines in Ankara in 1977-78 and 1979-80 crop seasons are shown in Figure 6. In the 1977-78 season there was a difference of more than one (0-9 scale) between checks and winter lines and winter x spring lines showing that the standard varieties and winter lines had more winterhardiness than the winter x spring lines. In the 1979-80 crop season the differences in average leaf damage that occurred in standard varieties, winter and winter x spring lines were not significant indicating increased winterhardiness in the winter x spring lines in two years.

Earliness-- Earliness is frequently a desirable agronomic character, especially in dryland agricultural regions, to avoid late moisture stress. To measure earliness, heading date was recorded as number of days from January 1. The average heading dates for standard varieties, winter, and winter x spring lines in Ankara in 1977-78 crop season were 158.83, 159.56 and 158.41 days respectively (Figure 7).

Improve New High Yielding Varieties

The final product of a breeding program and an effective factor in increasing production are improved high yielding varieties. The Turkish National Winter Cereal Program released six new cultivars in 1979. These varieties are listed below.

Haymana 79-- A winter bread wheat cultivar. Developed at the Central Anatolian Regional Agricultural Research Institute in Ankara from Sut^5 - Ag cross. The main characteristic of this variety is resistance to the three rusts.

Gerek 79-- A winter bread wheat cultivar developed at Eskisehir Agricultural Research Institute from the cross Menk"S" x My 48 - 4/14/Yy 305. This variety has field resistance to the rusts, common bunt, and loose smut.

Kirkpinar 79-- A facultative bread wheat cultivar developed at the Edirne Agricultural Research Institute from the 63-112-66-2 x 7C cross. This variety is resistant to loose smut, common bunt and stripe and stem rust. It is moderately resistant to leaf rust.

Gokgol 79-- A spring durum wheat cultivar developed at the Trakya-Marmara Regional Agricultural Research Institute in Istanbul from the B.Bal x BY_E^2 - Tc cross. Resistant to common bunt, moderately susceptible to stripe and stem rust.

Tunca 79-- A facultative durum wheat cultivar developed at the Edirne Agricultural Research Institute from a Fata Sel. 185-1 x 61-130-Leeds cross. Resistant to common bunt and loose smut, moderately resistant to leaf and stem rust, and moderately susceptible to stripe rust.

Cakmak 79-- A semi-dwarf facultative durum wheat cultivar developed at the Çetnral Anatolian Regional Agricultural Research Institute in Ankara from a Uveyik 162-61-130 cross. Resistant to loose smut and common bunt. Field resistance to the rusts.

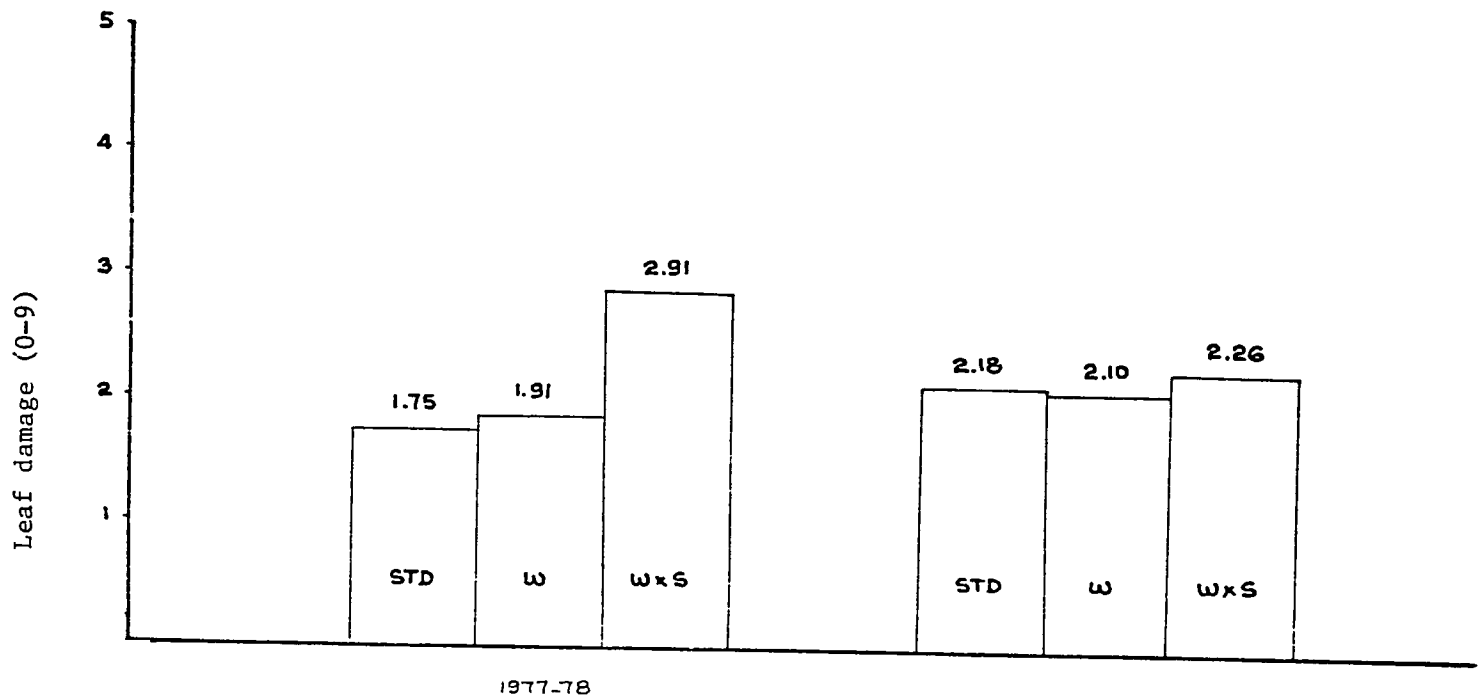


Figure 6. Average leaf damage observed in standard varieties, winter and winter x spring lines, Ankara, 1977-78.

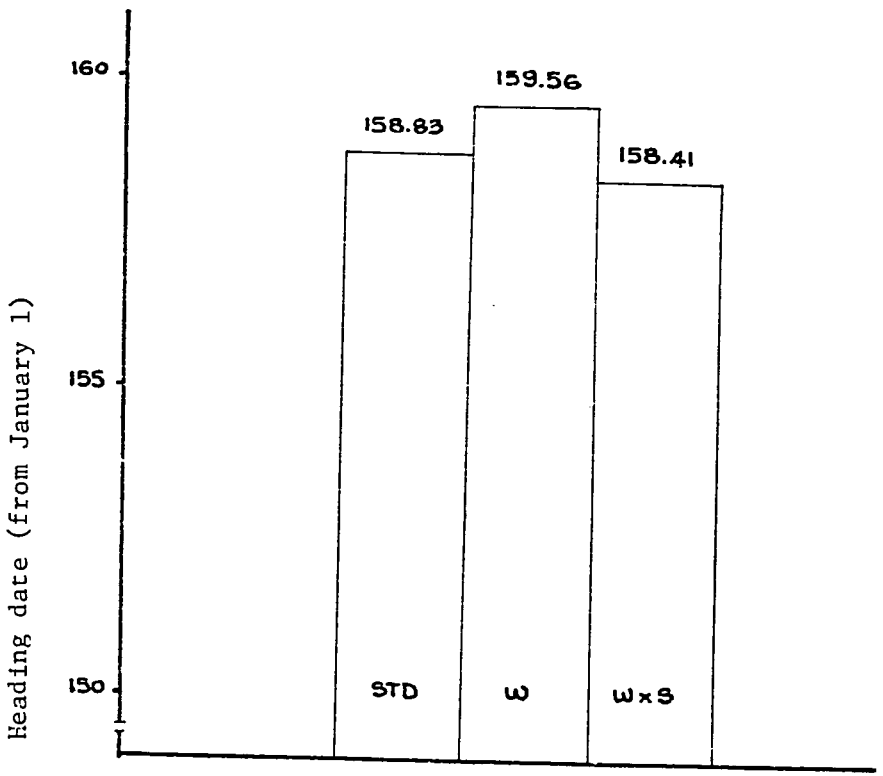


Figure 7. Average heading dates of standard varieties, winter and winter x spring lines, Ankara, 1977-78.

A METHOD FOR RAPID GENERATION ADVANCE IN SPRING CEREALS

J. S. Quick and M. S. McMullen
United States

Abstract

New techniques being used to develop new cultivars in 5-6 years will be discussed. They include utilization of winter nurseries, glasshouse facilities and early generation yield and quality testing.

Plant breeders are constantly seeking ways to improve their procedures for cultivar development. Many factors contribute to increases in genetic gain, and evaluation of genetic gain over time is important. Genetic gain per year (Gy) as expressed by Eberhart (4) is influenced by a selection differential, years per cycle of selection, additive genetic variance among lines tested, and the square root of the phenotype variance. Years per cycle of selection is the time interval from when parents are crossed until selections from their progeny are available for crossing again. The impact of y on Gy is direct and large, and the reduction of y is one of the most important ways to improve the productiveness of plant breeding programs. Ten years is the generally accepted time period for cultivar development, but a hungry world no longer allows that much time (Burton, 1980). New plant culture techniques, the use of winter nurseries and greenhouses and improved disease and quality evaluation techniques have reduced the time required for cultivar development. Soybean cultivars are developed in Iowa (6) and hard red spring wheats developed in North Dakota (7) according to eight year plans. The most recent durum wheat cultivar, "Vic", developed at North Dakota was produced in six years (16). Utilization of single seed descent (1, 19, 21) alone or combined with selection for certain traits (8) should shorten cultivar development time. The haploid technique, as exemplified by the methods developed in barley (11, 15), also has reduced the time from hybridization to the genetic homozygosity required for final testing.

This paper describes another rapid method for generation advance to decrease cultivar development time to five years without significantly reducing the final evaluation phase or jeopardizing agronomic performance, quality characteristics, or disease resistance of the cultivar. This program also could be used to incorporate specific traits more rapidly into germplasm for parents of future cultivars. Some recent developments allow such a proposal.

The most critical discovery was the field application of a night-interruption phenomenon utilizing artificial light (3). Utilization of the night-interruption phenomenon hastens the development

Agricultural Experiment Station, North Dakota State University

of long-day (daylength sensitive) cereals during short-day regimes during the October-March period in California and Arizona. Plant development and seed production can be shortened by about 30-60 days which allows: a) delayed planting from early November to late November or early December, and b) harvest and subsequent planting in North Dakota by May 1 rather than June 1. The shortened period allows an additional generation between August and November in North Dakota greenhouses and subsequent return of seed to North Dakota by the normal planting date.

The second important factor was the development of rapid, repeatable, and effective quality screening methods (18) requiring small amounts of grain and simple equipment. These methods allow selection for yellow semolina color and gluten strength in the F_2 generation of durum wheat. Screening for seedling disease resistance (9), gibberellin insensitive semidwarfism (8), and other grain or seedling traits is possible in the F_2. Effective selection in F_2 greatly reduces the population size and increases the frequency of desirable genotypes for subsequent generation advance and evaluation.

The third consideration is the availability of additional genetic information. Johnston et al. (10) have shown that semolina color is controlled almost exclusively by additive gene effects. Lukach (13), Quick and Donnelly (17), and Leisle and Baker (12) have provided evidence that gluten strength is predominantly additive, relatively simply inherited, and highly heritable. Genetic information available for simply inherited seedling disease resistance traits (9) allows effective F_2-F_3 selection. Recent studies have shown that F_4 and earlier generation yield testing can be effective (14, 20). Utilization of this information allows more rapid progress by placing more reliability upon fewer tests.

An additional requirement for more rapid generation advance is the availability of additional funds and facilities, especially at critical planting, harvest, and evaluation periods. The durum and oat production, processing, and marketing industries of the United States have helped provide these funds.

The five-year plan being utilized by the durum wheat breeding program in North Dakota is outlined in Table 1. The five years include the time the parents are grown for hybridization and a complete three-year final evaluation program. The total time requirement could be reduced to four years by reducing the final three-year evaluation phase to two. A four-year plan would be justified by a severe disease epidemic or other urgent needs.

The program includes three generations/year in each of the first two years. The tightest schedule is between harvest of the F_2 and planting the F_4 in Arizona. More research is needed to determine the effects of harvesting immature seed on semolina color and gluten

Table 1. The North Dakota five-year plan for durum wheat cultivar development.*

Year	Date planted	Location	Generation	Possible tests
1	Sept. 1, 1977	Fargo greenhouse	Cross	-
1	Jan. 10, 1978	" "	F_1	-
1	May 10, 1978	ND field	F_2	Height, maturity, diseases, semolina color, gluten
2	Aug. 10, 1978	Fargo greenhouse	F_3	Stem rust, height (GA), discard low quality lines
2	Dec. 1, 1978	Arizona field with lights	F_4	Height, daylength reaction, uniformity
2	May 10, 1979	ND field	F_5	Grain yield, other agronomic, disease, color and gluten
3	Oct. 1, 1979	Mexico field	F_6	Seed multiplication and purification
3	May 10, 1980	ND field	F_7	Complete final evaluation, regional tests
4	May 10, 1981	"	F_8	Final evaluation, regional tests, preliminary multiplication
5	May 10, 1982	"	F_9	Final evaluation, regional tests, large scale multiplication, release to certified seed growers

*The schedule is illustrated with a program that began in 1977 and has produced lines for regional tests in 1980 and cultivar release in 1982.

strength expression. Further evaluation of the effectiveness of F_2 yield evaluation with spaced plants, e.g., the honeycomb method (5) also is needed. The F_2 plants are space planted at 2 to 4/30 cm^2 and will yield 6 to 10 g/plant under North Dakota dryland conditions. The evaluation of remnant seed from F_2 plants for quality analysis, disease reaction, or other traits allows a drastic reduction in Arizona winter nursery space requirements and increases the frequency of desirable genotypes among materials returned to North Dakota for F_5 yield tests. Growing the F_3 generation in the greenhouse prior to the F_4 winter nursery also allows an increase in homozygosity for the first yield test (87.50 to 93.75%). The F_3 plants are grown in 15 cm pots (5/pot and 1 pot/F_2 family) and each plant produces 10 to 15 grains. Seed from each selected F_3 plant is sown in Arizona in single 1 meter rows spaced 50 cm apart. Over 100 g of seed is produced under irrigation to allow 2-3 locations, two replicates, and two rows 2.5 m long and 30 cm apart per entry. The F_3-derived F_5 lines are arranged in an augmented design, and systematically arranged checks or a moving mean can be used to select for grain yield. The lines for the winter increase in Mexico are chosen based on F_5 grain yield, agronomic, and disease performance, and F_2 and F_5 gluten and endosperm color tests. Additional quality data and seedling disease reactions are obtained during the winter prior to the final regional yield testing phase. Adequate seed (20 kg) is obtained in Mexico for eight regional yield tests in North Dakota and Canada and six drill strip locations in North Dakota for final quality (5 kg per entry/location required) and demonstration tests. Multiplication of selected lines is begun in the Arizona winter nursery (0.1 ha each), and concurrent with the final two years of regional evaluation, about 135 MT (5000 bu) of seed will be produced in North Dakota for distribution to certified farmer seed producers.

Examples of the utilization of the above method are provided from North Dakota durum wheat and oat breeding programs. In the durum wheat program two crosses were made between a medium height, weak gluten line and two tall, strong gluten lines. About 100 medium height F_2 plants/cross were selected, 10 seeds per plant were sown in 15 cm pots and thinned to five after emergence, and remnant seed was evaluated for gluten strength by the modified SDS-sedimentation method (17). About 35% of the F_2 families were selected and grown in Arizona. Additional selection was done in Arizona for plant height and about 165 F_5 lines (representing 66 F_2 plants) were grown in a preliminary yield test at Langdon, ND, in 1979. The F_5 test provided data on grain yield, test weight, kernel weight, lodging, maturity, plant height, disease reactions, glume color, and gluten strength. The nine most promising lines were increased in the Mexico winter nursery during 1979-80, and following further quality and seedling disease evaluations, six lines were entered into regional yield tests and drill strips in North Dakota and Canada in April 1980. If the lines continue to show promise, further testing, seed multiplication, and release in 1982 will follow.

In the oat breeding program, resistance to crown rust is one of the most important objectives. Several crosses have been made between

high yielding adapted lines or cultivars and sources of rust resistance. The F_2 plants are selected for stem and crown rust resistance, barley yellow dwarf virus resistance, plant height, and straw strength. The F_3 seeds are planted in pots, evaluated for stem and crown rust reaction, and harvested for Arizona planting. Additional selection is done for kernel morphology, straw strength, and plant height among F_2 families, F_3 families, and F_4 plants. F_4 families in the F_5 generation are grown in single 2 m panicle rows at Fargo. This material is planted relatively late in the season and spreader rows are inoculated with stem rust race 31 and crown rust races 264B and 326 to provide uniform rust infection. Susceptible lines are discarded and the remaining lines are evaluated for relative maturity, plant height, straw strength, groat percentage, and protein percentage. Selected lines are advanced to a two-row, two replicate preliminary yield trial at two locations. Using the greenhouse and Arizona nurseries reduces by two years the time from crossing to preliminary yield testing.

Summary

Reduced cycle time is an important factor influencing rate of genetic gain and cultivar development. Recent achievements in night-interruption with artificial light, the development of rapid, accurate quality tests utilizing small sample sizes, the availability of additional genetic information, and an increase in financial support have allowed the development of a more rapid cultivar or parental development scheme. A five-year plan was outlined, and examples of durum wheat and oat improvement illustrated. Suggestions were made for further research to improve the method and further reduce cycle time and increase rate of genetic gain.

References

1. Brim, C. A. 1966. A modified pedigree method of selection in soybeans. Crop Sci. 6:220.
2. Burton, G. W. 1980. New varieties developed faster. Crops and Soils 32(4):29.
3. Ebeltoft, D. C. 1976 Utilization of the night-interruption phenomenon to hasten the seed increase of long-day cereals during short-day regimes in California and Arizona. Ph.D. Thesis, Oregon State University, Corvallis, OR.
4. Eberhart, S. A. 1972. Techniques and methods for more efficient population improvement in sorghum. p. 197-213. In N. G. P. Rao and L. R. House (ed.). "Sorghum in the Seventies", Oxford and IBH Publishing Co., New Delhi, India.
5. Fasilas, A. 1973. A new approach to breeding superior yielding varieties. Pub. No. 3. Dept. Gen. Pl. Breeding. Arist. Univ. of Thessaloniki, Greece.
6. Fehr, W. R. 1976. Description and evaluation of possible new breeding methods for soybeans. World Soybean Research. p. 268-274.
7. Frohberg, R. C., L. D. Sibbitt, R. H. Busch, and J. D. Miller. 1973. Olaf -- a short strawed, high yielding hard red spring wheat variety. N. D. Farm Res. 30(4):12.

8. Gale, M. D. and R. S. Gregory. 1977. A rapid method for early generation selection of dwarf genotypes in wheat. Euphytica 26: 733-738.
9. Gough, F. J. and N. D. Williams. 1963. Inheritance of stem rust reaction in two durum varieties, Acme and Mindum. Phytopath. 53:295-299.
10. Johnston, R. A., J. J. Hammond, and J. S. Quick. 1978. Gene effects for semolina color in six durum wheat crosses. Agron. Abst. p. 54.
11. Kasha, K. J. and E. Reinbergs. 1972. The haploid technique in barley breeding. MBTA Technical Quarterly 9, No. 3:128-130.
12. Leisle, D. and R. J. Baker. 1973. An evaluation of quality testing in durum wheats. Proc. of Symposium on Genetics and Breeding of Durum Wheat, Bari, Italy. pp. 549-559.
13. Lukach, J. 1980. Gluten strength evaluation in durum wheat. M.S. Thesis. North Dakota State University, Fargo, ND.
14. O'Brien, L., R. J. Baker, and L. E. Evans. 1978. Response to selection for yield in F_3 of four wheat crosses. Crop Sci. 18:1029-1033.
15. Park, S. J., E. Reinbergs, E. J. Walsh, and K. J. Kasha. 1974. Comparison of the haploid technique with pedigree and single seed descent methods in barley breeding. In: Haploids in higher plants, advances and potential. Proc. of the First International Symposium, Guelph, Ontario, Canada.
16. Quick, J. S. 1977. Durum improvement progress and regional test results. Crop Quality Council Wheat Quality Conference Report pp. 7-12.
17. Quick, J. S. and B. J. Donnelly. 1980. A rapid test for estimating durum wheat gluten quality. Crop Sci. (in press)
18. Quick, J. S., S. Vasiljevic, R. Johnston, and Y. Holm. 1980. Recent durum quality evaluation advances. Proc. Int. Wheat Breeding Symposium, Madrid, Spain.
19. Riggs, T. J. and A. M. Hayter. 1975. Practical aspects of the single seed descent method in barley breeding. Proc. of Third International Barley Genetics Symposium, Garching, Federal Republic of Germany 708-717.
20. Seitzer, J. F. and L. E. Evans. 1978. Yield gains in wheat by the pedigree method of selection and two early yield tests. Z. Pflanzenzuchtg. 80:1-10.
21. Wilson, T. and J. S. Quick. 1978. Comparison of some selection methods for yield in Triticum turgidum L. var. durum. Agron. Abst., p. 67.

PHENOTYPIC EXPRESSION OF ISOZYMES OF DIFFERENT WHEAT VARIETIES

Katarina Borojevic
Yugoslavia

Abstract

Common wheat cultivars from different geographical regions were screened for 11 isozymes: esterase (Est), peroxidase (Prx), glutamic oxalate transaminase (Got), leucine amino peptidase (Lap), phosphoglucomutase (Pgm), phosphoglucose isomerase (Pgi), acid phosphatase (AcPh), alkaline phosphatase (AlkPh), malate dehydrogenase (Mdh), 6-phosphate-dehydrogenase (G-6-Pgdh), and isocitric dehydrogenase (Icd). They were characterized for phenotypic zones. Genetic polymorphism was found in three esterase zones, two peroxidase zones, and two zones of phosphoglucoisomerase. These three systems thus appear to be suitable for differentiation of cultivars of hexaploid wheat.

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Introduction

Most studies of isozymes in hexaploid wheat were done for location and evolution of isozyme structural genes (Brewer, 1970; Jaaska, 1969, 1976). A very extensive summary of recent studies was given by Hart & Langston (1977). According to Hart (1979) the chromosomal locations of more than 40 isozyme structural genes have been determined in these studies.

Yaghoobi (1977) studied the mode of inheritance of enzyme variants of 8 isozymes of diploids and tetraploids in five species: *Triticum boeoticum*(2n=14), *T.urartum* (2n=14), *T. dicoccoides* (2n=14), *T. araraticum* (2n=14) and *Aegilops speltoides* (2n=14). Yaghoobi studied the following systems: Malate Dehydrogenase, Glutamic Oxaloacetate Transaminase, Phosphoglucomutase, 6-Phosphogluconate Dehydrogenase, Phosphoglucoisomerase, Peroxidase, and Esterase.

However, in hexaploid wheat there was not much information about mode of inheritance of the enzyme variants. Therefore, the main objective in the initial stage of this project was to develop systems which will be suitable for differentiation of cultivars of hexaploid wheat.

Material

Forty different cultivars and lines of *Triticum aestivum* vulgare were chosen for the study of allozymes in wheat (Table 1).

The first group represents cultivars of wheat from different geographical regions, but all were grown for several years in an

Institute of Biology Faculty of Natural Sciences, University of Novi Sad.

Table 1. Cultivars of wheat screened for different isozymes.

Cultivar	Country	Description
Anza	Mexico CIMMYT	Short straw, high yielding varieties.
Cajeme	"	
Yecora	"	
Siete Cerros	"	
Lerma Rojo	"	
Super X	"	
Inia	"	
Mara	Italy	Mediterranean type
San Pastore	"	
Mutant 70	Yugoslavia/Italy	Mutants of San Pastore resistant to *Puccinia recondita tritici*.
Mutant 71	"	
Mutant 72	"	
Biserka	Yugoslavia	Short straw, high yielding varieties, similar to Mediterranean type.
Sava	"	
Drina	"	
Sremica	"	
Novosadska (NRS)	"	
Bankuti	Yugoslavia	Old continental type, winter hardy varieties.
Stara Banatka	"	
Atlas 66	USA	High straw, winter hardy, very good quality, high yielding.
Hyslop	"	
Maris Nimrod	Great Britain	High yielding
Kavkaz	USSR	Medium straw height, winter hardy, very good quality.
Aurora	"	
Lr1	Canada	Resistant to different races of *Puccinia recondita tritici*.
Lr1+	"	
Lr2	"	
Lr2+	"	
Lr3	"	
Lr9	"	
Lr9+	"	
Lr13	"	
Lr14	"	
Lr17	"	

Table 1. Continued

Cultivar	Country	Description
NS 51-26 (Super X x Aurora)	Yugoslavia	Short straw, high yielding varieties.
NS 52-35 (Super X x Kavkaz)		
NS 51-51 (S13 x Aobakomuglu) x Sava		
NS 51-24 (Bezostaya x Backa) x S. Cerros		
NS 51-31 (Kavkaz :: Siete Cerros)		
NS 50-01 (S-15 x Acciaio) x San Pastore		
NS 50-96 (Leone x Acciaio) x Sava2		
NS 2568 (NS-646 x Berostaja) x SK-35		

experimental field at the Institute for Agriculture Research, University of Novi Sad, Yugoslavia.

The second group are Lr lines with different genes for resistance to Puccinia recondita tritici in the same genetic background, that of the variety Selkirk. The third group are NS lines, the best yielding lines from the Institute of Agriculture Research at Novi Sad obtained by crossing parents from different geographical regions and selecting for high yield. Therefore, the first group represents cultivars adapted to different geographical regions; the second group represents cultivars with different genes in the same genetic background; and the third group represents cultivars with combinations of genes from different regions.

Enzyme extracts were obtained from leaf tissue of 12-day old seedlings. The horizontal gel electrophoretic technique was applied.

The gels were prepared using either tricitric acid buffer system, (Poulic, 1957; Marshal and Allard, 1970), 12.8% starch at pH 7.7; or a histidine system used in Dr. Allard's laboratory (unpublished), 12% starch at pH 7.0.

The gels were assayed following procedures of Shaw & Koen (1968), Shaw & Prasad (1970), Selander et al., (1970), modified for wheat seedlings.

Results and Discussion

Screening for the 11 isozymes esterase (Est), peroxidase (Prx), glutamic oxalate transaminase (Got), leucine amino peptidase (Lap), phosphoglucomutase (Pgm), phosphoglucose isomerase (Pgi), acid phosphatase (AcPh), alkaline phosphatase (AlkPh), malate dehydrogenase (Mdh), 6-phosphate-dehydrogenase (G-6-Pgdh), and isocitric dehydrogenase (Icd), showed that the electrophoretic patterns of Pgi, Px, and Est are the most suitable as genetic markers in hexaploid wheat.

Pgi had 3 distinguishable zones. The mode of inheritance of three bands in zone III showed an allelic difference, whereas three bands were governed by one locus with 2 alleles (Fig. 1).

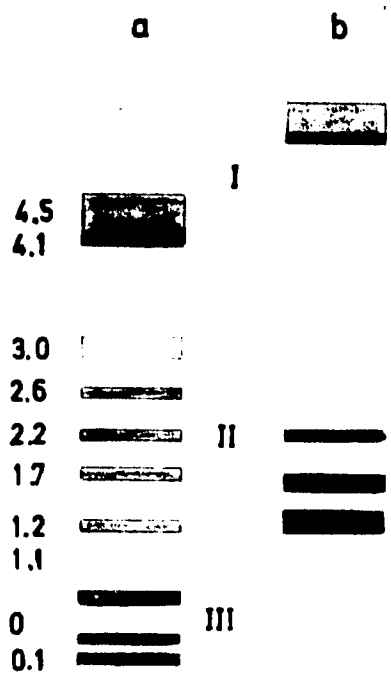

Figure 1. Banding pattern of phosphoglucose isomerase (PGI).

Cathodal peroxidase (cPx) had seven zones. The pattern of inheritance was done for zones I and IV. The first zone had a monohybrid type of inheritance with co-dominant gene action. The fifth zone showed monohybrid segregation but with dominant gene action (Fig. 2).

Esterase (Est) had seven zones. Genetic studies were done for zones I, II and VII. Variation in zone I may be governed by two genes at two different loci. In zone II, bands at 6.25 and 6.80 had dominant inheritance. The same indication was obtained for zone VII. (Fig. 3).

Glutamic oxalate transaminase (Got), leucine amino peptidase (Lap), phosphoglucomutase (Pgm), acid phosphatase (AcPh) gave good electrophoretic patterns with distinguishable bands. Genetic polymorphism was observed to some extent only for acid phosphatase. All other isozymes did not show polymorphism in the materials tested.

Six phosphogluconate dehydrogenase (6-Pgdh) gave a good pattern and distinguishable bands. Polymorphism was observed, but not many gels were run for this isozyme.

Malate dehydrogenase (Mdh), alkaline phosphatase (AlkPh), isocitric dehydrogenase (Icd) did not give very readable gels which could be used in genetic studies of hexaploid wheat.

Results from testing wheat cultivars for the isozymes being studied showed that genetic polymorphism existed at 3 esterase loci, 2 peroxidase loci and two loci in Pgi. These three isozymes could be used to differentiate cultivars of hexapoid wheat.

Acknowledgement

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References

Brewer, F. J. 1970. An introduction to izozyme techniques. Acad. Press, New York.

Hart, G. and P. J. Langston. 1977. Chromosomal location and evolution of isozyme structural genes in hexaploid wheat. Heredity 39(2):263-277.

Hart, G. E. 1979. Evidence for a triplicate set of glucosephosphate isomeres structural genes in hexaploid wheat. (in press).

Marshall, D. R. and R. W. Allard. 1970. Isozyme polymorphisms in natural population of *Avena fatua* and *A. barbata*. Heredity 25(3):373-382.

Poulic, M. D. 1957. Starch gel electrophoreses in a discontinuous system of buffers. Nature 180:1477-1479.

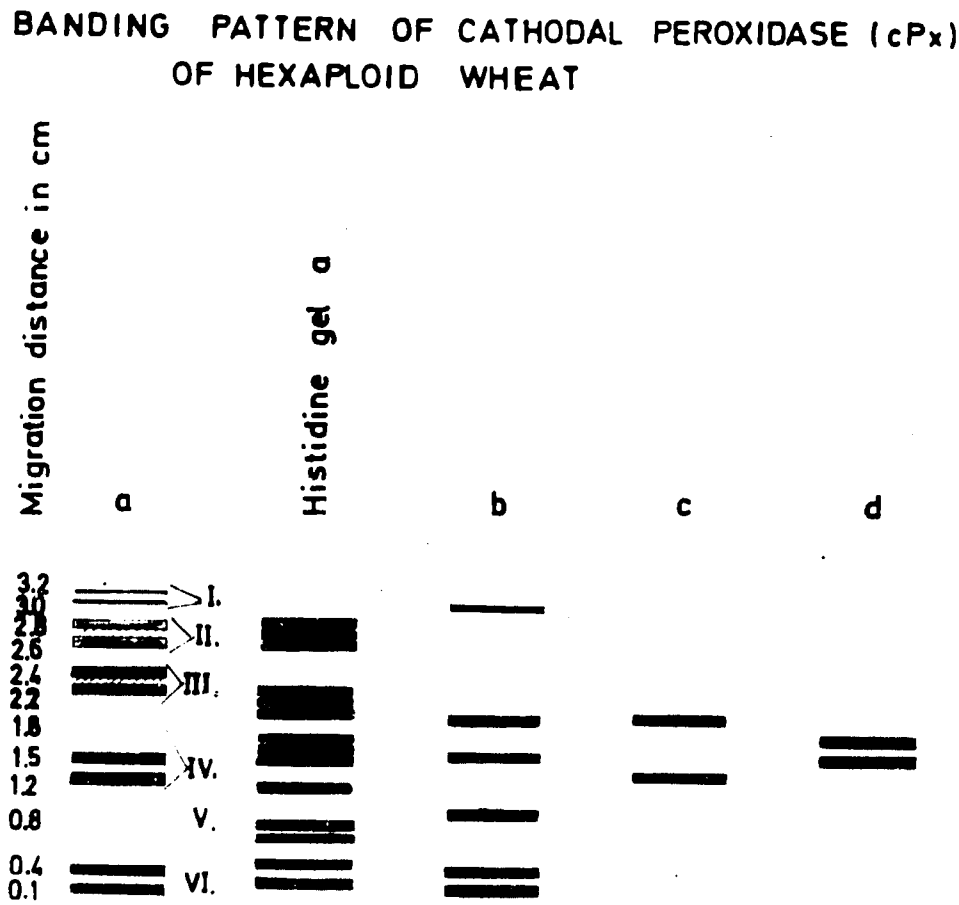

Figure 2. Banding pattern of cathodal peroxidase (cPx) of hexaploid wheat.

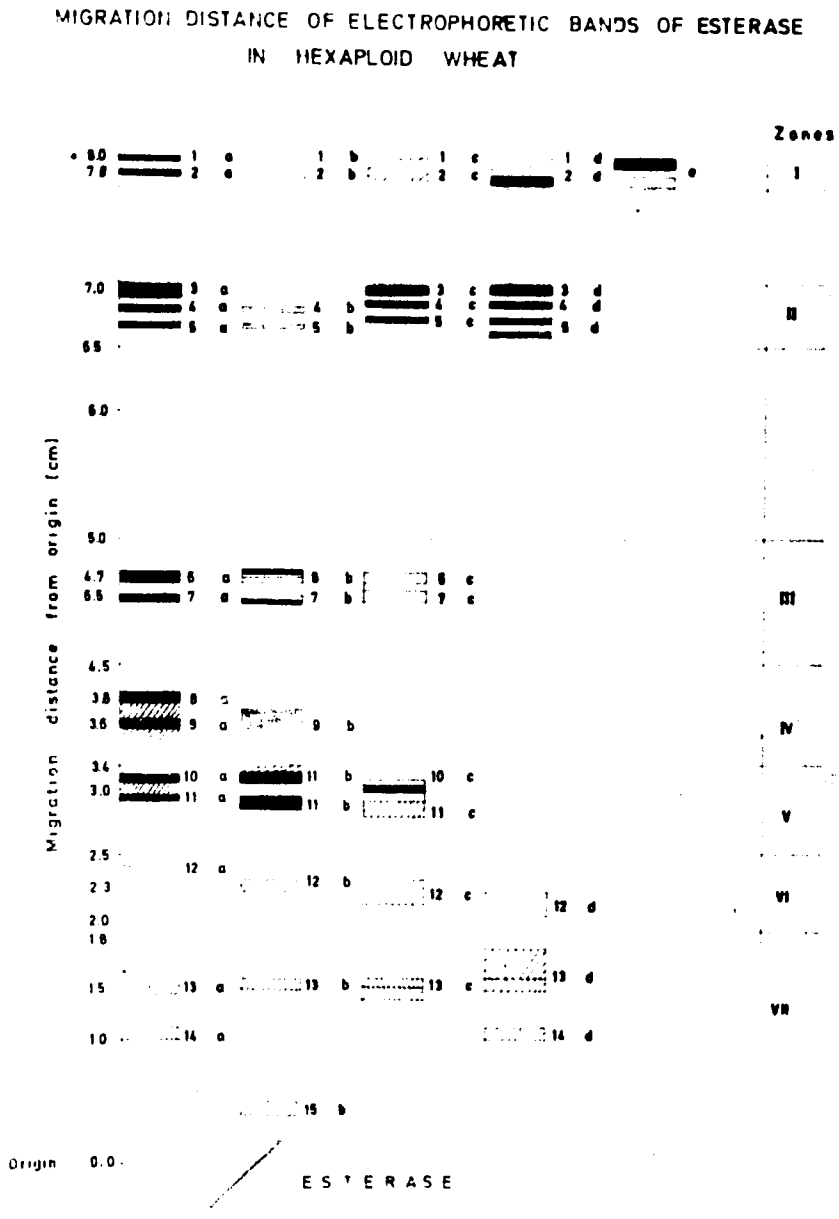

Figure 3. Migration distance of electrohoretic bands of esterase in hexaploid wheat.

Selander, R. D. 1976. Behavior and genetic variation in natural populations. Ames. Zool.10:53-66.

Shaw, C. R. and A. L. Koen. 1968. Starch gel electrophoresis of enzyme. Chromatographic & Electrophoretic Techniques. Ivor Smith (Ed.) 2nd edition, Intersciences, New York.

Shaw, C. R. and R. Prasad. 1970. Starch gel electrophoresis of enzymes. A compilation of recipes. Biochem. Genet. 4:297-320.

Yaaska, V. 1969. Electrophoretic studies of seedling phosphatases, esterases and peroxidases in the genus Triticum L. Eesti NSVTA TAINET, Biol. 18(2):170-183.

Yaaska, V. 1976a. Alcohol dehydrogenase in polyploid wheat and in their diploid relatives. On the origin of tetraploid wheat. Genetika, U.S.S.R. 12:22-28.

Yaghoobi-Saray. 1979. An electrophoretic analysis of genetic variation within and between populations of five species in the Triticum-Aegilops complex. Ph.D. thesis, UC Davis, June 1979.

EFFICIENT METHODS OF POPULATION MANAGEMENT AND UTILIZATION IN BREEDING WHEAT FOR MEDITERRANEAN-TYPE CLIMATES

C. O. Qualset and H. E. Vogt
United States

Abstract

This paper will describe methods used in breeding wheats for a Mediterranean type climate in the U.S. This environment represents a transition region for winter and spring wheats and represents a large proportion of the world wheat producing areas. Some unique constraints on genotype are imposed, but at the same time great flexibility in breeding approaches are possible. Wheats requiring vernalization (winter wheats) and those that do not (spring wheats) can be well adapted to this environment. Autumn or winter plantings predominate and the main restriction is that the cultivars developed must be relatively photoperiod insensitive. This environment offers opportunities for rapid plant breeding advance because two generations can be grown each year in the field. Breeding strategies will be discussed with examples, as used at Davis, California including: 1) selective and nonselective population management schemes (including bulk populations and family vs. individual selection), 2) selection criteria for yield improvement and yield stability (e.g., crop canopy, growth habit, yield components, disease resistance), and 3) efficient methods for use of "shared germplasm" populations.

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A large portion of the world's wheat is produced in regions having mild winter temperatures, winter rainfall, and hot dry periods in the spring and early summer. The Mediterranean region is typical of this area. Varieties with spring growth habit are well-suited to autumn or winter planting in such areas because little or no freezing resistance is needed. Photoperiod insensitive types are generally most productive because varieties requiring long days flower sufficiently late that they are damaged by high temperatures and/or limited water supply during the maturation period. At the same time, most of these environments have low temperatures adequate to vernalize varieties with winter growth habit. Thus, these environments are transitional between the classical spring and winter wheat regions. Most of the wheat producing areas of California on the west coast of the United States are typical of the Mediterranean-type climate. It is the purpose of this review to relate some of the results and experiences in breeding and introducing wheats in California, as well as offer some suggestions for selection criteria and breeding methodology. We hope some of our experiences will be useful in other regions having similar climates.

Department of Agronomy and Range Science, University of California--Davis.

Background

Wheat breeding has been in progress in California since 1904. The basic germplasm was first introduced by the Spanish in the Missions settlement period of the 18th century. Later, Australian germplasm was introduced, including varieties used widely in production and many used as parental stocks (Suneson and Briggs, 1941). This germplasm, and the work of five decades of plant breeding, virtually disappeared after California's first severe stripe rust (*Puccinia striiformis*) epiphytotic in 1961 (Halisky et al., 1962). Varieties from the Rockefeller Foundation Mexican program were quickly adopted because of their resistance to this disease. First, standard-height varieties--Lerma Rojo, Yaqui 50, and Nainari 60--were used. Shortly thereafter short-statured varieties were introduced. Of these, Lerma Rojo 64, Sonora 64, and Pitic 62 were the first to become commercially established. Pitic 62 became the dominant variety in the Sacramento Valley until 1974 when a new stripe rust race caused extreme damage. Lerma Rojo 64 and Sonora 64 were rapidly replaced by the second group of short-statured varieties released by INIA-CIMMYT in Mexico. Siete Cerros 66 had a brief popularity, but its stripe rust susceptibility and variable grain quality prevented widespread adoption. Likewise, Sonora 64, also being susceptible to stripe rust, was rapidly replaced by INIA 66, which was well accepted by the milling industry and became a dominant variety.

With the exception of Cajeme 71 and Tanori 71, which are currently grown to a limited extent, the varieties grown in California at present were not released as commercial varieties in Mexico, but are selected from CIMMYT materials or were developed in California. This includes the varieties INIA 66R, Portola, Yecora Rojo, and Anza and several varieties introduced by private seed companies which were selected from CIMMYT materials, and Shasta which was bred in California. Anza was released in 1971 (Qualset et al., 1973) and rapidly became the dominant variety in the irrigated production areas, except the Imperial Valley in the far southern part of the State. In 1980 it was grown on 48 percent of the area (of a total crop of 466,000 hectares) and Yecora Rojo was the second most prevalent variety (22 percent). Both Anza and Yecora Rojo were selected as advanced lines from CIMMYT materials. Anza is very similar, if not identical, to the variety Mexicani (Sudan), Karamu (New Zealand), WW 15 (Australia), Mohgan 1 (Iran), and T4 (South Africa). Thus, this genotype is very widely adapted and has become an important variety in many of the areas where varieties with spring growth habit are winter-grown crops. Seed stocks have been exported from California in large quantities in recent years, providing in large measure for the rapid adoption of the variety in southern Spain and Portugal. Yecora Rojo is a red-seeded variety which is very similar to Yecora 70, a white-seeded variety, and the red-seeded Cajeme 71. These three varieties and Northrup King Probred are all from the famous CIMMYT "Bluebird" Cross (II 23584) and have had a very significant impact on California wheat production. As with Anza, seed stocks of these varieties were exported to other countries. Anza has been used extensively in rainfed production as well as rainfed areas, whereas Yecora Rojo, being shorter (70 cm compared to 90 cm for Anza under good growing

conditions), has not been generally as successful as Anza in rainfed conditions.

In California, as well as many areas of the world, wheat production has dramatically increased in recent years. Table 1 shows three-year mean yields and production for the past 20 years. With yields per hectare increasing 2.76 times area planted increasing almost 2 times the total increase in production in the 1977-79 period was 5.5 times greater than the 1959-61 base period. Most of this production is under irrigation, but about 100,000 hectares each year are under rainfed conditions (alternated years of wheat and fallow). Even with this large increase in production there still remain significant problems that must be considered for further yield increase and yield stability. In the remainder of this paper we will mention briefly topics which are of major interest in the breeding of wheats for Mediterranean-type climates.

Table 1. California wheat production for 1980 and 3-year means since 1959-61.

Period	Grain Yield		Hectares	
	kg/ha	% of 1959-61	000's	% of 1959-61
1959-61	1610	100	137	100
1962-64	2020	125	116	85
1965-67	1930	120	121	88
1968-70	2600	161	193	141
1971-73	3340	207	217	158
1974-76	3940	245	350	255
1977-79	4440	276	274	200
1980	4970	309	466	340

Selection Criteria

Disease resistance. Stripe rust is the primary disease on wheat in California. It devastated the crop in 1961 (Halisky et al., 1962) and 1974 (Line, 1976) in the Sacramento Valley. Currently used varieties are resistant and we are attempting to introduce additional genes for resistance by backcrossing. The derived lines are sent to various cooperators around the world where stripe rust is severe and where the varieties used in California are susceptible. Lines resistant at these locations are retained for further breeding and in storage in case they are needed in California because of shift in virulence frequencies in the pathogen population. Stripe rust resistance from Sonora, the old variety of Spanish origin, was transferred by backcrossing to Siete Cerros 66 and Sonora 64. Leaf rust is occasionally important, but usually the crop is well toward maturity when the disease attacks. Stem rust was formerly the most damaging disease of wheat in California, but since the development of resistant varieties in the 1930's and 1940's, the incidence of this disease declined until it no longer was important. We have not seen it in nurseries of production fields for about 20 years.

The second most important disease is barley yellow dwarf virus (BYD). This disease is aphid-transmitted and occurs in variable severity throughout the whole state. Yield losses in wheat can approach those incurred by barley with early and heavy infection (see Schaller and Qualset, these proceedings). The popular variety Anza has measurable resistance (Qualset et al., 1973) which, in part, may contribute to its widespread adaptation in California and elsewhere. CI 13232, a second source of resistance identified by J. C. Williams at Davis in the early 60's, has been useful in the breeding program and apparently differs from Anza in genes for resistance (Topcu, 1975). Our current program emphasizes selection of resistance levels higher than that found in the two above-mentioned varieties. An international cooperative program is presently under development by CIMMYT to emphasize breeding for resistance in developing countries.

We consider speckled leaf blotch caused by Septoria tritici to be our third most important disease. S. nodorum has been found on one occasion in California (Brownell, 1979), but is not important at this time. In 1975 a rather severe and general infection occurred in the breeding nurseries at Davis. All breeding materials were scored for reaction and from among some 40,000 breeding lines good resistance was found in populations which had European winter wheat parents, including Cleo, Tadorna, and Nudif TP 250, which were being used for stripe rust resistance (Gul et al., 1975). Resistant lines, both early and late maturing, were subsequently confirmed to be highly resistant by controlled greenhouse and field inoculations by Brownell and Gilchrist (unpublished). They have also established that resistance was simply inherited (unpublished results). These genes are being backcrossed into several adapted varieties and several resistance sources are being recombined in a germplasm development project.

Bunt (Tilletia caries) resistance had been incorporated in the old California varieties, and the disease, which was formerly very important in the State, had been practically eliminated by 1960. The Mexican varieties (except Siete Cerros 66) are susceptible and we are backcrossing resistance into several of the varieties. Seed treatment has not been applied routinely since mercury compounds were removed from use and there have been several instances of severe yield losses due to bunt in recent years. Bunt resistance is, therefore, an important selection criteria, but the disease cannot be considered a devastating one at this time.

Other diseases present include powdery mildew and root rot caused by several organisms. Powdery mildew was expected to be important on the short-statured wheats which produce a very dense canopy, but this is rarely observed in the common wheats and only occasionally on durum wheats. The root rots no doubt cause yield losses each year but these are not well documented.

Grain yield and yield components. Whereas disease resistance is an extremely important stabilizing factor for maintiaing high productivity, the attainment of higher yield levels requires some modification of expression of yield components. For Mediterranean-type environments, optimum relationships among yield components

is due to genes controlling photoperiod response. Pugsley (1973) has proposed that a gene for vernalization requirement could be advantageous to photoperiod insensitive wheats. The projected advantage being that a narrow flowering period could be reached by a wide range of planting times. In particular, early planting could be done with reduced danger of freezing damage because of precocious culm elongation and flowering. Pugsley, working in Australia, developed WW 33 wheat to test this hypothesis. This variety is basically a white-seeded, vernalization-requiring WW 15 (=Anza) type. The vernalization requirement advances the planting date about 30 days while still reaching flowering at the optimum date (Pugsley, 1973).

We have studied WW 33 and Anza for several years in California. With early planting (about November 1, compared to December 1 to 15 as standard) the varieties are indistinguishable in flowering time and grain yield. Table 2 shows the four-year means of WW 33 and Anza from the International Winter Wheat Performance Nursery grown at Davis where these varieties were included as local checks. The two winter wheats Blueboy and Bezostaya I represent the performance level expected for winter wheats under these conditions.

Table 2. Grain yield of WW 33 in the International Winter Wheat Performance Nursery at Davis, California.

Variety	4-year mean kg/ha da.	Head date past 31 Mar '78
WW 33	7070	29
Anza	7130	29
Blueboy	5020	43
Bezostaya I	5040	50

When these varieties are tested through a 40-km distance of the central valley of California (Table 3) with normal December planting, WW 3 performs very well, and may even show some advantage over Anza. We believe the Pugsley's concept warrants extensive evaluation and hope that research will be forthcoming from other areas on this idea. We have developed several isoline pairs of vernalization and nonvernalization requiring lines (including, Yecora Rojo, INIA 66R, Pitic 62 and Siete Cerros 66) which should be available for testing in 1982. Incidentally, the Blackhull winter wheat lines developed in Texas (Atkins et al., 1962) might be used for breeding and testing the roll of vernalization genes. Extra Early Blackhull has a strong vernalization requirement, but is very photoperiod insensitive (Klaimi and Qualset, 1973).

Table 3. Performance of WW 33 wheat in the Central Valley of California - 3-year mean grain yields.

Location	WW 33	Anza	WW 33 as % of Anza
Kings	7270	7300	100
Fresno	7280	7000	104
Sacramento	6920	6930	100
Yolo	7720	7060	109
Sutter	7470	7390	101
Mean	7340	7130	103

are still subjects of continuous discussion and debate with MacKey (1966) and Donald (1968) providing the most comprehensive discussions and models for plant design for various major kinds of environments.

For several years at Davis we were impressed by large spike size as a means to obtain a high number of seeds per unit area. This character no doubt influences many plant breeders, but we now think it may be over-emphasized as a selection criterion. Admittedly, we hold this view with some reservations especially in view of the results obtained by McNeal et al. (1978) in a spring-planting environment where individual yield components were used as selection criteria. In that study selection progress for increased number of seeds per spike resulted in substantial yield improvement and also for seed size as a correlated character. These results were obtained for a single hybrid population and a similar study has not been done in a Mediterranean climate. Well-designed experiments of the type done by McNeal are badly needed.

Our model for selection now emphasizes heavy tillering with a spike of moderate to large size. We do not emphasize high number of seeds per spikelet at present because of the usual irregularity of seed size in spikes having high number of seeds/spikelet. This results in some loss during harvest and lower flour yield upon milling. We tend to select for large seeds, but this is not a heavily weighted yield component during selection. We must admit that our thinking is dominated by the Anza-type as a model. We consider Anza to be the "Gaines" of the spring wheats because of similarities in plant type and high yielding ability. Under California conditions Anza has rather small erect spikes, 3 to 4 seeds per spikelet, high tiller number, and uniform seed size on both early and late tillers. Careful documentation of the growth characteristics of the Anza-type under a wide range of environments still needs to be done and such an analysis should provide interesting approaches to increase grain yield further.

Morphophysiological characters. Without question, genetic control of flowering response is the major factor controlling adaptation of wheats to Mediterranean-type environments. Because the crop is planted in the fall or winter it comes to flowering while the days are increasing in length. Thus, genotypes which flower under short days or are independent of daylength in their flowering response are required. Secondly, the winters in most of the Mediterranean-type environments are mild so that winter hardiness is not generally important. At the same time, however, freezing temperatures do occur and if this occurs after an extended warm period there can be severe damage to spike primordia, or fertility is reduced if the spikes are at anthesis during the freezing period. The problem then is to find a wheat which avoids (or resists) the freezing period and matures early to avoid water stress damage in rainfed production.

Even though photoperiod insensitive spring wheats are desirable there can be fine-tuning of varieties to local conditions. Thus we see variation in vernalization responses among both photoperiod sensitive and insensitive spring wheats (Peterson and Levy, 1972), but the greatest variation in flowering response among spring wheats

The next most important morphophysiologic character in wheat, after optimum flowering time is achieved, for Mediterranean-type climates is plant height. Breeding programs steadily reduced plant, but prior to the Norin-10 derived short-statured lines, the varieties grown were too tall. In California, Ramona 50 was the dominant variety for many years. It was tall, a standard-height variety, but surprisingly, we found it to have a major height-reduction gene which was independent of the two Norin 10 genes (Fick and Qualset, 1973). Combinations of this gene and the Norin 10 genes produce a wide range of plant height that can give "talldwarf" types for use in rainfed production, where the one- and two-gene short-statured types are often too short. Without doubt reduced plant height is a major selection criterion and it seems clear that additional genes for short stature are desirable. Unfortunately, the extreme height reduction, for example, of Olesen Dwarf or Tom Thumb, does not appear to be advantageous under highly productive conditions. More promising, in our view, are genes that exist in so-called standard-height or tall varieties. Considerable breeding effort is warranted to move these genes into more desirable genetic backgrounds.

Finally, we would like to mention briefly the modification of canopy architecture as a selection criterion. The Donald ideotype recommends short erect leaves because a higher density of spikes can be accommodated with adequate light penetration into the canopy. Theoretical analyses have not supported this concept because leaf erectness is believed to be advantageous only with leaf area index of 5.0 or higher (Duncan, 1971). This value is not achieved in many environments. There are widely known sources of leaf erectness in wheat, and in some instances, as with NK Produra durum wheat, very high yields are attained. Irrespective of the results of simulation modeling studies, we believed that modifying leaf size and angle was worthy of investigation. Beginning in 1970 we have used a sphaeroccocum wheat, PI 190982, as a source of leaf erectness. Our goal is to develop systematically erect leaf wheats with as high a yield level as possible. PI 190982 is very poorly adapted to our conditions, giving yields about 60 percent of normal. After one cycle of selection for erect leaf and good agronomic type, the grain yields of the derived lines were about 80 percent of normal (De Carvalho and Qualset, 1978). Second cycle materials are still under selection and have not been evaluated. The sphaeroccocum source has very erect leaves, but is associated with lateness, tallness, and dense spike which contribute to difficulty in breeding.

Liguleless-auricleless wheats provide another method for obtaining erect leaves. We identified such a durum wheat in the U.S.D.A. world collection and were successful in transferring the character to common wheat. Long erect leaves have been obtained in an INIA 66 background, with an added interesting feature of extremely large spikes. These materials have not been advanced to yield testing as yet.

A discussion of selection criteria in wheat breeding for Mediterranean climates would not be complete without mention of

environmental stress resistance. In particular, drought resistance is a primary concern. We have not had a systematic effort in this area and have tended to concentrate on irrigated production. We believe drought avoidance (Qualset, 1979a) under rainfed production is the approach that will give the greatest benefit; this might be reached through genetic modification of growth periods as mentioned earlier. This might not be the case for salinity resistance, also a dehydration problem. We have recently started a rather ambitious program in developing wheats with improved resistance to soil salinity and saline irrigation water (including seawater). R. Kingsburg and E. Epstein at Davis have used seed production under tank culture at salinity equivalent to 80 percent of seawater as a selection criteria for salinity resistance (Epstein et al., 1980). This method was successful, as judged by the fact that the salt resistant Karchia wheat from India was identified from the World Collection without prior knowledge of its salinity reaction or of its presence in the World Collection. Hybrid populations are currently being investigated in field and tank culture conditions and it remains to be seen if greater salinity resistance than exists in Karchia, Ramona 50, or other well-known wheats can be obtained. A major goal of our current work is to develop simple and reliable methods for characterizing salinity response for use as selection criteria in field conditions.

Breeding Strategy

The strategy taken to incorporate desirable genes for improvement in the selection criteria is worthy of much consideration. There are several considerations in developing a breeding strategy, including (1) genetic structure of the population to be ultimately used as a cultivated variety, (2) mating design, (3) selection methods, and (4) population management. These are not unique to breeding for Mediterranean-type climates but some aspects of application may be more appropriate in these climates.

Superimposed upon these components is the question of whether the breeding program emphasizes stabilization of performance, or, at the other extreme, emphasizes maximum productivity with little consideration for stability. In the latter case the goal may be to develop varieties for very specific conditions. While the areas having Mediterranean-type climates certainly differ in many characteristics, it is obvious that there are many similarities so that a genotype which performs well may appear to be widely adapted (viz. the CIMMYT II8156 derivatives, such as Siete Cerros 66, Indus 66, Kalyansona, etc.). Thus, the areas having Mediterranean-type climates can, in a broad sense, be considered a single adaptation region. Breeding for maximum performance without selection for stability can be a worthwhile effort as evidenced by the early successes of the CIMMYT program (actually its predecessor, the Rockefeller Foundation program) in Mexico where selection was done at two locations which favored photoperiod insensitive flowering behaviour.

If stabilization of performance is a major concern, the question is often raised about how stabilization can be attained. We take a rather restricted and simplistic view on this issue. Breeding for stability can be done by systematically removing the defects

of an adapted variety by introducing genes through backcrossing. Thus a variety that is successful can be made more successful, that is, reducing year-to-year or site-to-site variation by introducing disease, shattering or lodging resistance. Genes for such characteristics do not improve the inherent yielding ability of the variety and a yield ceiling is accepted.

In California this method was successfully applied over several decades of breeding (Briggs and Allard, 1953). By 1961, the year of the stripe rust epidemic, only a few cultivars were grown, and one, Ramona 50, was planted on about 90 percent of the area. It was the product of several successive backcross programs. Other varieties included White Federation 54, Big Club 60, Poso 48, Baart 46, and Onas 53. Throughout this period of stabilization breeding there was little evidence of mean yield advance in the absence of diseases. However, the varieties provided improved stabilization against yield losses due to bunt, stem rust, and Hessian fly. The varieties were typically populations of 100 or more F_3 or F_4 composited lines after the last backcross. They were released to growers without yield-testing because the agronomic characters were so similar to the recurrent parent.

Genetic structure of varieties. The question of stability should also be specifically addressed to the components of a breeding strategy, mentioned earlier. A decision must be made concerning the genetic structure of the population to be designated as a variety before a breeding program can be initiated. In addition to backcrossing "stabilizing" genes into a recurrent parent, there have been considerable research and debate about the role of intra-population heterogeneity in conferring stability of performance (Jain and Qualset, 1975). Most recently there has been a resurgence of interest in multiline varieties. Multilines are believed to stabilize performance by stabilizing the gene frequencies for virulence of pathogen populations (Browning et al., 1979). We are watching with great interest the performance and stability of the Kalyansona and Sonalika multilines recently released in India. In general, heterogeneous populations of wheat have rarely had higher productivity than the best component in the population (Qualset, 1968). Increased stability has been detected in experiments, but usually the benefit is so small that rather sophisticated statistical tests are required to detect it (e.g. see Qualset and Granger (1970) for an example in oats). Genetic heterogeneity in varieties may stabilize yields under production conditions, but the evidence is still meager.

Mating design. Backcross breeding is an example of a mating design widely used in wheat breeding, but biparental crosses are probably the most common mating system still used, but when multiple objectives (selection criteria) are to be accommodated simultaneously it appears that mutiple-parent crossing schemes are valuable (Jensen, 1970) for parent-building and direct selection of varieties. Such mating designs may involve intercrossing of biparental F_1's, threeway crosses, chain crosses, or by wind or manual pollination of male sterile lines by a large number of pollen parents.

In connection with the question of choice of mating designs, the question of how to choose parents for breeding is often raised. We do not have a clear answer to that question when the desired character is not easily observed, as for example grain protein or lysine content. When the character is observable we recommend hybridization with one or more adapted varieties followed by intercrossing the F_1's or a single backcross. Additive gene action is no doubt the preponderant form of gene action so the concepts of Grafius (1965b) have utility in directing crosses toward favorable gene frequencies. When the character(s) under selection is not easily detected and a large sample of potential parents are available, it appears that hybridization of a group of candidate parents to a constant parent is useful. The graphic representation of the regression of F_1 progeny performance on the nonrecurring parent provides an easy method to identify parents that contribute genetic effects to the F_1 in the cross with a selected parent (see Qualset, 1979b; example on lysine content). This is but one array in a diallel mating design, and a full diallel may be used if the number of parents are small and if it is critical to determine whether the potential parents have different genes for the character under study.

Choosing parents for use in hybrid wheat varieties (F_1 grown as commercial crop) is even a more difficult problem because it is desirable to determine the combining ability of each potential parental line before tedious conversions to cytoplasmic male sterility or pollen fertility restoration are done. We have used generation means (parental, F_2, three-way F_1) to estimate genetic effects that could be used in a prediciton of F_1 performance (Bailey et al., 1980). In an experiment involving four parents the predictions of actual F_1 yields were remarkably accurate. Specific combinations were identified that gave good heterosis. This method appears worthy of further experimental testing.

Selection method. The decision of method of selection is closely related to the method of population management and the selection unit (i.e. single plant or family performance) to be discussed in the next section. The conceptual decision in developing a breeding strategy has to do with whether the immediate objective is to release a variety for production or to develop improved germplasm for future breeding. The latter is often called parent-building. Both objectives are essential for a successful breeding program. The essential ingredient is "recurrency," that is, small improvements from one cycle of selection are built upon in a subsequent cycle of hybridization and selection. This is especially important when multiple selection criteria are considered simultaneously. The probability for success under these conditions can be improved by increasing population size during selection and early-generation and multisite testing. The highly successful CIMMYT wheat program relies heavily on this form of recurrent selection. Jensen (1970) provided an excellent example of how short-term and long-term goals can be integrated in a single program with his diallel selective mating scheme. We recommend that all wheat breeding programs be developed within the concepts of recurrent selection.

Immediate goals in variety development can be met within the frame-work of recurrent selection by pedigree selection or backcross integration of new genes. This provides reasonably good assurance that varieties will be developed to secure the production of the crop. For long term improvement, recurrent selection in complex hybrids can reasonably expect to improve overall productivity and/or stability. For example, in California we have selected the cultivars INIA 66R, Yecora Rojo, and Anza as recurrent parents for introducing specifically needed characters. At the same time, a complex hybridization program for increasing productivity is underway. Current results indicate that the latter will be successful; two lines, UC 353 and UC 355, have yielded 10 percent more than Anza, our high-yield standard. This illustrates a major disadvantage of the backcross program: The recurrent parents are outdated when better varieties are isolated. However, the new varieties can simply be substituted as recurrent parents thus maintaining a steady, but slow, progress in genetic improvement.

Population management. In the previous sections of this paper we have outlined in brief some of the conceptual aspects of wheat breeding for Mediterranean-type climates. Operational aspects of applying selection criteria have received a great deal of attention in wheat breeding over many years. This includes details of population size, plot size, planting density, selection of whole plants vs. single spikes, selection on family performance, early-generation vs. late-generation testing, bulk populations vs. progeny rows, and off-season nurseries. Decisions about most of these factors are not different for Mediterranean-type climates than other types and the form of population management used in a program has depended more on individual preferences than on genetical or statistical aspects of expected genetic gain or sampling theory. Perhaps the major distinction in breeding for Mediterranean-type climates is that a second crop can be grown in the field in a summer season following the main crop in most areas.

We have developed a system of handling breeding materials at Davis that suits our needs, and is quite efficient in use of labor and space. Some of the features might be useful to other programs where resources are limited. Figure 1 shows schematically how materials from a variable base population may be handled. The base population, which may be a biparental F_2 or a population from a complex hybridization series (composite-cross) may be handled in one of three ways: (1) pedigree selection for progeny rows, (2) a bulk population perpetuated without selection, called a random bulk, or (3) a bulk population perpetuated with selection, called a selected-bulk.

1. Pedigree selection. Our pedigree selection scheme differs little from that used by many programs for the last 5 or 6 decades. We will briefly review it here to show how it integrates with a comprehensive population management scheme. We select a single spike from each selected plant in the base population (e.g. F_2). The seed from this spike is used to plant a single 2.5-meter row in the next generation. From each population we select an arbitrary number of spikes, based on phenotype. Presently our plot seeder

is set up for four-row plots so we select spikes in multiples of four so that these can be planted in individual rows without identification of the lines within each four-progeny (four-row) group. In the progeny rows (e.g. F_3), selection is first done on the basis of visual appearance of the row (i.e. the phenotype of the family of plants). From within the selected progeny rows single spikes are selected, again in multiples of four. These spikes are individually threshed and used to plant individual progeny rows. Thus in the F_4 generation we have 4, 8, 12 or more-row plots derived from a single progeny row in the F_3. These progenies form a family group. If a F_3 progeny row is exceptionally uniform and desirable it is harvested en masse after the spikes are selected and considered for yield-testing in the next generation. Progeny families and yield tests plots are carried simultaneously so that lines with good performance in yield trials are available as individual progeny rows as a seed source for the next generation of yield-testing. This is illustrated in the left side of Figure 1. Family groups, as in an F_4 generation, are evaluated by three-stage visual evaluation: (1) as a family group, (2) as individual progenies within the group, and (3) as individual plants within a progeny row. Typically four spikes are selected from a single progeny row within a family group. These spikes then generate a family group for the next generation. Again, highly uniform progeny rows are harvested for yield evaluation after the single spikes are selected. This process is repeated until practical homozygosity is achieved. Selections are usually evaluated in yield trials for two years at Davis, and those with outstanding performance are advanced to statewide regional trials.

Two generations can be grown in the field at Davis with the following sequence: June harvest, July planting, October harvest, November planting. When the second crop generation is grown in the field, the above pedigree scheme works best when (1) the hybrid is made in the field in May, (2) F_1 plants grown from July to October, (3) F_2 plants grown in the normal winter nursery, (4) F_3 progenies grown in the summer nursery, and (5) F_4 progenies grown in the normal winter nursery. This sequence is desirable as the summer crop is not well-suited for selection because plant growth is not normal due to high temperatues. We grow the crop in rows spaced 70-cm apart for convenience of irrigation and cultivation. Selection can be applied in the F_2 and F_4 generations very effectively and these generations are grown in the most desirable environment for selection.

Table 4 gives an example of this scheme used in the development of Shasta wheat. The hybrid was made in 1970 and the variety released in 1976 after three years of statewide testing. Seed multiplication for this variety also utilized southern and northern California locations to obtain maximum seed multiplication.

We did an experiment which incorporated comparative tests of some of the methods used in our pedigree selection program (Thakare and Qualset, 1978). Briefly the study was done as follows: Ninety-six random F_3 lines from the cross Bluebird 2 x Anza were grown in a two-replicate experiment. The plants were spaced 30 cm apart

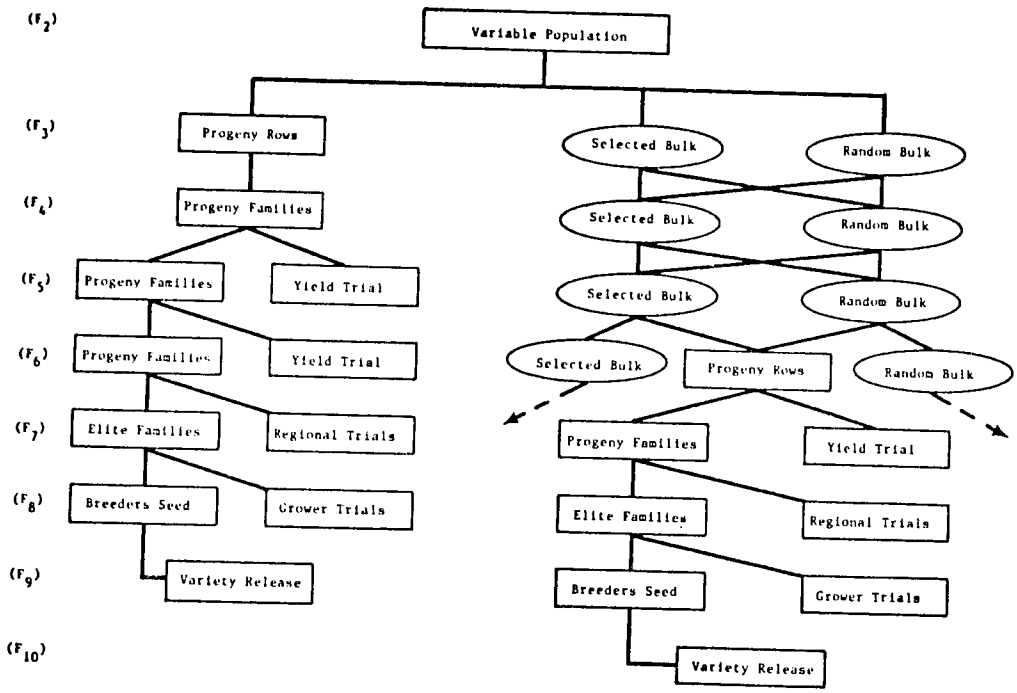


Figure 1. Schematic representation of three population management methods for wheat breeding utilizing pedigree selection and bulk populations.

between and within rows. In the first replicate five plants were harvested at random from each F_3 line; in the second replicate, two plants were selected from each line on the basis of visual appearance. The plants were individually harvested and the grain weights taken. In the F_4 generation, 36 F_4 families were selected at random from the 66 F_3 lines. A two-replicate yield trial with normal seeding density was planted at two locations. In each F_4 family group there were three random lines and two derived from visual selection in the F_3.

Table 4. Development of Shasta wheat from the cross of Inia 66 x Anza.

Year	Season	Generation	Operation
1	May 1970	F_0	Cross made (Davis)
1	July-Oct 1970	F_1	10 plants bulk-harvested
2	Nov 1970-June 1971	F_2	Space-planted, spikes selected
2	July 1971-Oct 1971	F_3	Progeny rows, 4 spikes selected/ progeny
3	Nov 1971-June 1972	F_4	Family groups
4	Nov 1972-June 1973	F_5	Family groups and yield trial
5	Nov 1973-June 1974	F_6	Family groups and regional trial
6	Nov 1974-June 1975	F_7	Family group and regional trial
7	Nov 1975-June 1976	F_8	Family group and regional trial Variety released
8	Nov 1976-May 1977	F_9	Breeders seed increased (El Centro)
8	May 1977-Sep 1977	F_{10}	Foundation seed produced (Tulelake)
9	Nov 1977-June 1978		Commercial production

The F_4 experiment was evaluated by assuming four different selection strategies in the F_3 plants: Individual selection was applied by selecting the top 33 percent of the plants based on F_3 plant grain yield. Within family selection was done in each family and the best plant was selected. For the family selection method the best 33% of the F_3 lines were selected on the basis of mean yield of the F_3 line. Finally, combined selection was applied by selecting the best 33 percent of the F_3 lines as with family selection, but only the best plant within each F_3 line was selected. The performance of the selection procedures was judged by the performance of the selected F_3 plants in the F_4 generation. The selection procedures were judged as comparisons over the performance of the mean of the random F_4 population. The results in Table 5 show that in all cases there was a numerically better selection response when visual selection was applied. The difference between random and visual selection appeared to be real for family and combined selection. Individual plant selection gave significant response in both random and visually selected groups, but the most response was obtained for the combined selection procedure. This procedure shows an advantage for visual selection, a conclusion not reached by several other workers. The advantage was not great, but the results surely indicate that visual selection is not detrimental. It does not add additional effort to the selection process

so we believe it is a worthwhile effort. These results are consistent with the procedures we have outlined for handling the pedigree selection program. We do not measure the yields of single plants, but rely directly on visual selection.

Table 5. Single plant selection for grain yield.

F_3 Selection method	F^4 response $\bar{x}$ > random F^4	
	Random	Visual
1. Individual	4.21*	4.73*
2. within Family	3.43	2.87
3. Family	1.01	6.52**
4. Combine: Family and Individual	3.56	7.47

*P < 0.05, ** P < 0.01 for comparison to random F_4.
From Thakare and Qualset (1978).

2. Bulk populations. We have previously defined a bulk population "to include any population of genotypes that is synthesized by mixing them or by employing one or more cycles of hybridization and is propagated or used without any artificial selection" (Jain and Qualset, 1975). There is ample evidence that bulk populations maintained without selection are dynamically changing in gene frequencies for certain loci, either with or without obvious direct effects of the loci on fitness. This is especially true in wheat populations that are variable for plant height (Khalifa and Qualset, 1974, 1975). In the case of plant height the less fit individuals are the short-statured ones which are desired for irrigated and many rainfed production conditions.

For bulk populations to be useful in breeding it is obvious that it is desirable that they be managed to prevent the loss of valuable alleles. This leads to the concept of selected bulk populations (SB). By this we mean that bulk populations are advanced from one generation to the next by applying some form of selection that will presumably make the population more valuable in the future. We use the term random bulk population (RB) to indicate that no conscious selection is applied during the perpetuation of the population (Tee and Qualset, 1975).

Figure 1 shows how SB and RB populations are advanced and ultimately used in variety development. The populations are advanced to near homozygosity and individual plants are selected (as single spikes) for progeny row analysis as conducted in the pedigree selection side of the diagram. The RB and SB methods of population management are efficient in use of land and labor, but it may take a year or two longer to complete the release of a variety by this method. In addition, there are fewer opportunities to observe a family and its progeny using this method than with the classical progeny row method. A further disadvantage we have experienced is that a low frequency of progenies worthy of retention is found in the first or second generations of progeny rows and family groups taken from RB or SB populations. The progeny row method tends to eliminate grossly defective types in the early generations, such as the F_3

and F_4 so that observations in later generations are concentrated on materials that are generally more desirable.

Figure 1 also shows that RB and SB populations are interconnected. Selection can be applied to an SB if it appears desirable, if not, it is harvested en masse and effectively becomes a RB. Likewise populations following the RB track can become SB populations at any time. This flexibility is highly desirable because it allows the breeder to take advantage of opportunities for selection, but does not require tedious selection if the characters, such as disease resistance, are not expressed. For example, it was mentioned that short-statured plants are at a selective disadvantage in bulk populations. To retain these genotypes it is quite simple to select and bulk the short-statured plants to make an SB in the F_2 or F_3 generations, the population can be carried for several future generations without selection as a RB population.

The concept of SB populations also introduces another aspect of population management. This concerns the question of how SB populations should be advanced. The single-seed descent method as proposed and applied by Goulden (1939), Brim (1966), and Grafius (1965a), has been under investigation in a number of programs as a combined pedigree and bulk population method. This method, strictly applied, requires that a single seed of each plant be harvested and the whole sample of seeds composited for producing the next generation. This assures random perpetuation of the population and perhaps is the surest way of producing RB population with minimal natural selection.

SSD will result in reduced population size because of inevitable mortality of plants from one generation to the next. A loss of genetic variance, as a result of the restricted sampling procedure and steady reduction in population size over time, has been advanced as another disadvantage of the SSD method (Sneep, 1977). This latter defect of the method has not been borne out by experimentation (Tee and Qualset, 1975). Regarding effective population size, a slight modification in the individual plant sampling procedure can be applied to overcome this. C. A. Brim, one of the early proponents of SSD in soybean breeding, selects a single pod from each plant. This gives one to three seeds per plant and reduces the probability that a progeny line will be lost by random mortality during generation advancement. Wade Dewey at Utah State University introduced us to his method of population advancement in 1968. He selects single spikes from desirable plants in his bulk populations. Seeds from these spikes are threshed and composited to produce the next generation. We have adopted this single-spike descent method for our SB populations. It overcomes the disadvatage of steady reduction in population size and has the advantage of providing opportunity for evaluation of several seed and spike characters in the field at harvest time or later in the laboratory. Single-spike descent has a further advantage in a practical breeding program. A large enough sample of seeds is obtained from a population so that a sample can (1) be retained in storage, (2) be planted in several locations, (3) be subjected to various selection pressures such as disease resistance screening nurseries, or (4) be used for germplasm sharing (discussed later).

We handle RB and SB populations in the following manner. An F_2 population, or other early generation population, is grown in 15-meter plots, planted in 4 rows each 30 cm apart. A normal seeding density is used, 80 to 100 kg/ha. This gives a population of about 1200 plants. In some instances where larger populations are desired two or more plots of each population are grown. For RB populations, the plots are harvested with a small-plot combine. SB populations are developed by either selecting spikes, about 200 per population, or by harvesting the population en masse and applying selection after harvest for seed size or seed color. We also use low planting density in an attempt to allow selection pressure for high tillering ability. Derera and Bhatt (1973) in Australia have developed an elaborate system of postharvest selection on seed size, shape, density, and color. Frey has used several other techniques in oats, including cutting plants to a uniform height to apply selection pressure for short stature and selection for seed width (Frey, 1967; Romero and Frey, 1966). Methods for SB population development are limited only by the imagination of the plant breeder. There are ample results to indicate that the methods are effective in changing gene frequencies. It has not been resolved how many generations of selection should be applied in SB populations to be useful in a practical breeding program. Experiments and the theory of change in gene frequency for recessive genes under selection have shown that there can be response to selection over a large number of generations. If bulk population breeding is applied as we show in Figure 1, then we propose that the number of generations for selecting and bulking be small, perhaps no more than three. Results from selection studies, such as McNeal et al. (1978) show rapid gain and little further gain after about the F_4.

Recently we evaluated a population, wheat Composite-Cross I (Suneson et al., 1963), that was subjected to selection for large, small, and intermediate seed size for 10 generations (Minella, 1979). Figure 2 shows that most of the genetic change in the population was attained by the F_5 generation.

The main points of emphasis in SB and RB development are (1) to advance toward homozygosity, and (2), in SB population development, to increase frequencies of several desirable characters with as little effort as possible. Since we are proposing that progeny line evaluation be applied in about F_5 generation, there is adequate opportunity for selection in progeny row evaluations. It is important to remember that there is little natural crossing in wheat so that selection on gene combinations existing in bulk populations does not lead to indefinitely long periods of selection response. Hybridization must be introduced into the populations to initiate the next cycle of recurrent selection.

Germplasm Sharing

Without doubt one of the major contributing factors to wheat improvement during this centruy has been the relatively free exchange of the world germplasm. This is extremely important for the Mediterranean-type climates because there is such a large production area having many common features. At the same time, many countries and cultures are transcended which have contributed to the

evolution of distinctive landrace forms. Most of these countries now have well-trained and ambitious plant breeders who can assume responsibility for variety development. A steady flow of germplasm through these countries is essential and the programs of UN/FAO and CIMMYT should be continued. For many of the countries, this is a transitional period from the time when plant breeders were not available to the present when the breeders are available and there is a national commitment to crop improvement. The concept of germplasm sharing needs to be cognizant of this transition since it affects the nature of the germplasm shared. We would like to comment on several aspects of germplasm exchange that have surfaced as important in our wheat breeding efforts in California. We will discuss the nature of the germplasm to be shared and how this can be done efficiently for mutual benefit of the donor and recipient programs, including a description of how we use the selected bulk population concept for shared germplasm.

"Fixed" germplasm. Homozygous and homogeneous materials are the most important source of germplasm to plant breeders. This is especially so if there is extensive documentation of unique genetic characteristics of the materials. These materials include varieties which have been grown extensively, new sources of genes for pest resistance, and advanced lines from breeding programs. Breeders can return information on the performance of these materials in exchange for the seed received. Fixed-line germplasm gives breeders the opportunity to control the introgression of new characters into adapted germplasm to fit their local needs. This encourages creativity among the breeders and to some extent will ensure that a broad genetic base of varieties is grown in a production region.

Variable populations. Because of the similarities among areas having the Mediterranean-type climate, variable populations can be exchanged and used directly in selection. CIMMYT has an extensive program of exchange of F_2 populations which are widely used by local breeders. The advantage for this form of exchange is that materials are immediately available for selection and little expense of advanced plant breeding skills are needed to create an effective variety development program. There are several disadvantages, including: (1) increased opportunity for disease migration, (2) transportation expenses for shipping large amounts of seed are high, (3) many of the populations will not fit local needs and will not be productive for selection, and (4) local breeders may come to depend upon this means as a source of breeding materials without exerting their creative initiative.

In wheat breeding it is not difficult to create large amounts of variable materials for sharing, thus there is some danger in overproducing variable populations so that the recipients cannot evaluate all of the materials properly. This raises the question of how to be more efficient in creating useful germplasm populations. Choosing parental materials again becomes an important problem. For certain characters, the methods outlined earlier in this paper can be used, especially the constant parent regression method where several broadly adapted varieties might be chosen as the recurring parent in crosses with a large sample of new source mate-

rials. If the new source materials are known to have new valuable genes, but are grossly unadapted to Mediterranean-type climates, they should be first used in a cycle of parent-building. The resulting materials would have better general adaptation and the loss of desirable genes would be less likely due to adverse combinations with undesirable genes.

McWhirter (1977), in discussing germplasm sharing, proposes that relatively small-scale genetic studies be done to evaluate the potential for a cross in future breeding. He suggests that a sample 25 to 80 SSD-derived homozygous lines be evaluated in a replicated test to estimate the population mean, variance, and heritability. This information, along with observations on the parents, can be used to determine whether there is potential for selection within a cross. Populations with low genetic variance would not likely be successful in selection, unless the population mean was high. McWhirter and Rose (1977) have demonstrated this method for a group of soybean populations. The advantage of this method is that homozygous lines may be selected from a population and distributed individually or composited and distributed as a bulk population.

Handling shared variable populations. Each wheat breeding program should direct most of its efforts toward local specific goals. At the same time, materials from other programs can be observed and utilized. It is important that this latter activity be done with little effort and expense. At Davis we continuously observe and use CIMMYT F_2 populations of common wheat, durum wheat and triticale. We have adopted the SB technique for these materials. Each population is grown in a 2.5-meter 4-row plot at a normal planting density. The populations are observed for disease reaction, maturity time, lodging, and shattering. If a population is strongly defective in any of these traits it is discarded. Populations that appear worthy of retention are then subjected to selection. Ten to 20 spikes are selected from each population and are threshed in bulk for planting as an F_3 SB population. For durum and triticale the bulked seed sample is examined, if the sample has a very high proportion of defective grains it is discarded. In subsequent generations the same procedure is used and whole populations are routinely discarded each generation. By this method the populations are maintained in a simple way and have the desirable features: (1) there is a steady increase in the frequency of desired characters within each population, (2) the population is advancing to homozygosity, and (3) the population is approaching homogeneity. After three generations of SB advancement, we isolate 12 to 24 progeny rows for more detailed observation before yield-testing. This procedure is highly flexible and can be modified to suit local needs; and importantly, it provides for maintenance of germplasm populations through seasons when there is no possibility for effective selection.

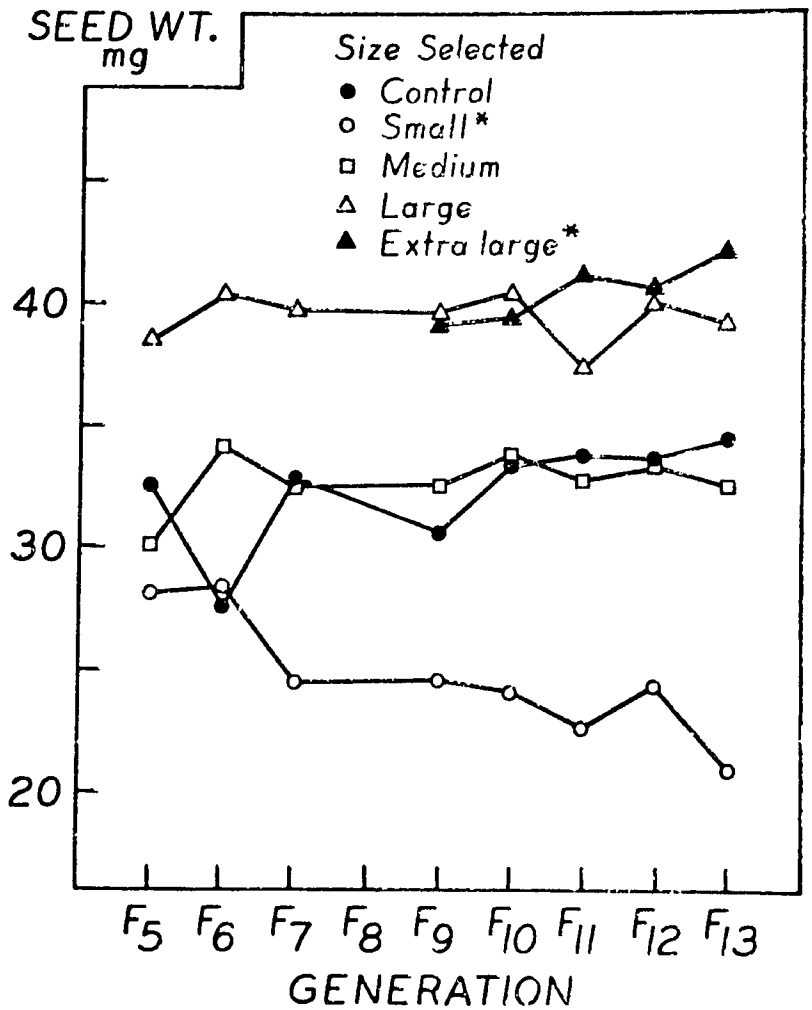


Figure 2. Mean seed weight of wheat Composite Cross I subpopulations selected for seed size by bulk screening through sieves of various sizes. Seed weight determined of all generations in a common environment (Minella, 1979).

Summary

A large portion of the world's wheat production comes from areas characterized by mild winters, winter rainfall, and hot, dry summers. Wheat varieties for these areas, broadly characterized as having Mediterranean-type climate, typically have spring growth habit and are planted in the fall or winter. The many similarities among areas having this climate-type offer many common objectives in wheat breeding and good opportunity for useful exchange of germplasm and information. California, on the west coast of the United States, has this type of climate and we have reviewed some features of the wheat improvement program as they may become useful to others. In addition to the usual disease, lodging and shattering resistance criteria in breeding, genetic control of flowering time has emerged as a major character for selection. Photo-period insensitive, vernalization-requiring types are worthy of extensive development and testing. We recommend that all programs have two major thrusts: (1) Stabilization breeding through defect elimination by backcrossing to an adapted parent, and (2) breeding for new character combinations and higher performance levels through recurrent selection. These thrusts can be integrated in a common program. The system of population management through integration of pedigree selection and bulk populations used in California was described. The concept of selected bulk populations where selected individuals are bulked for several generations appears to be efficient and useful. Germplasm sharing among programs as varieties, advanced breeding lines, or special genetic stocks is viewed as most desirable, although there are certain advantages to sharing genetically variable populations. If variable populations are shared we recommend handling them as small-scale selected bulk populations.

Literature Cited

Atkins, I. M., D. E. Weibel, and E. C. Gilmore,. 1962. Extra Early Blackhull, an unusual new strain of the "Blackhull" group of wheats. Crop Sci. 2:357-359.

Bailey, T. B., Jr., C. O. Qualset, and D. F. Cox. 1980. Predicting heterosis in wheat. Crop Sci. 20:339-342.

Briggs, F. N., and R. W. Allard. 1953. The current status of the backcross method of plant breeding. Agron. J. 45:131-138.

Brim, C. A. 1966. A modified pedigree method of selection in soybeans. Crop Sci. 6:220.

Brownell, D. H. 1979. Septoria diseases of wheat in California. M.S. Thesis. Univ. of California, Davis, 87 pp.

Browning, J. A., K. J. Frey, M. F. McDaniel, M. D. Simons, and I. Wahl. 1979. The bio-logic of using multilines to buffer pathogen populations and prevent loss. Ind. J. Genet. Plant Breed. 39:3-9.

De Carvalho, F. I. F., and C. O. Qualset. 1978. Genetic variation for canopy architecture and its use in wheat breeding. Crop Sci. 18:561-567.

Derera, N. F., and G. M. Bhatt. 1973. Population improvement through selection en masse for seed attributes in hybrid bulk of wheat. Proc. Fourth Int. Wheat Genetics Symp., Columbia, Mo. pp. 465-470.

Donald, C. M. 1968. The design of a wheat ideotype. Proc. Third Int. Wheat Genet. Symp. Aust. Acad. Sci., Canberra. pp. 377-387.

Duncan, W. G. 1971. Leaf angles, leaf area, and canopy photosynthesis. Crop Sci. 11:482-485.

Epstein, E., J. D. Norlyn, D. W. Rush, R. W. Kingsbury, D. B. Kelley, G. A. Cunningham, and A. F. Wrona. 1980. Saline culture of crops: a genetic approach. Science 210:399-404.

Fick, G. N. and C. O. Qualset. 1973. Genes for dwarfness in wheat, Triticum aestivum L. Genetics 75:531-539.

Frey, K. J. 1967. Mass selection for seed width in oat populations. Euphytica 16:141-149.

Goulden, C. H. 1939. Problems in plant selection. Proc. Seventh Int. Genet. Congr., Edinburgh. pp. 132-133.

Grafius, J. E. 1965a. Short cuts in plant breeding. Crop Sci. 5:377.

Grafius, J. E. 1965b. A geometry of plant breeding. Mich. Sta. Univ. Agric. Exp. Sta. Res. Bul. 7.

Gul, Azam, C. O. Qualset, and H. E. Vogt. 1975. Resistance to septoria leaf blotch of wheat in California. Univ. Calif. Agron. Prog. Rep. No. 70.

Halisky, P. M., J. D. Prato, B. R. Houston, and J. H. Lindt. 1962. Wheat yi[illegible] [illegible]uced in 1961 by stripe rust epidemic in central Califor[illegible]a. Ca[illegible] f. Agric. 16(1):5-6.

Jain, S. K. [illegible]nd C. [illegible] [illegible]ualset. 1975. New developments in the evaluation [illegible] theory [illegible] bulk populations. Proc. Third Intl. Barley Genetic[illegible] [illegible], [illegible]arching. pp. 739-749.

Jensen, N. F. 1970. A diallel selective mating system for cereal breeding. Crop Sci. 10:629-635.

Khalifa, M. A. and C. O. Qualset. 1974. Intergenotypic competition between tall and dwarf wheats (Triticum aestivum L.). I. In mechanical mixtures. Crop Sci. 14:795-799.

Khalifa, M. A. and C. O. Qualset. 1975. Intergenotypic competition between tall and dwarf wheats (Triticum aestivum L.). II. In hybird bulks. Crop Sci. 15:640-644.

Klaimi, Y. Y. and C. O. Qualset. 1973. Genetics of heading time in wheat (Triticum aestivum L.). I. The inheritance of photoperiodic response. Genetics 74:139-156.

Levy, J., and M. L. Peterson. 1972. Responses of spring wheats to vernalization and photoperiod. Crop Sci. 12:487-490.

Line, R. F. 1976. Factors contributing to an epidemic of stripe rust on wheat in the Sacramento Valley of California in 1974. Plant Disease Reporter 60:312-316.

MacKey, J. 1966. The wheat plant as a model in adaptation to high productivity in different environments. Contemp. Agric. 14:29-39.

McNeal, F. H., C. O. Qualset, D. E. Baldridge, and V. R. Stewart. 1978. Selection for yield and yield components in wheat. Crop Sci. 18:795-799.

McWhirter, K. S. 1977. Utilization of genetic variability in aut[illegible]g-amous plant species. Proc. 3rd Int. Congr. Soc. Adv. Breed. Res. Asia and Oceania, Canberra, Australia. Plant Breed. Papers 1:2c(i). pp. 1-9.

McWhirter, K. S., and I. A. Rose. 1977. A comprehensive breeding plan for soybean improvement. Ibid pp. 13-16.

Manella, Euclydes. 1979. Evaluation of ten generations of mechanical mass selection for seed size in wheat composite cross I. M.S. Thesis. Univ. Calif., Davis.

Pugsley, A. T. 1973. Control of developmental patterns in wheat through breeding. Proc. Fourth Int. Wheat Genet. Symp., Mo. Agric. Exp. Sta. Columbia, Mo. pp. 857-859.

Qualset, C. O. 1968. Population structure and performance in wheat. Proc. Third Int. Wheat Genetics Symp. Canberra, Australia. pp. 397-402.

Qualset, C. O. 1979a. Breeding for drought resistance in maize. Proc. 1st SAFGRAD Maize Workshop. Upper Volta.

Qualset, C. O. 1979b. Mendelian genetics of quantitative characters with reference to adaptation and breeding in wheat. Proc. Fifth Int. Wheat Genetics Symp., Indian Society of Genetics and Plant Breeding, New Delhi 2:577-590.

Qualset, C. O., J. C. Williams, M. A. Topeu, and H. E. Vogt. 1973. The barley yellow dwarf virus in wheat: Importance, sources of resistance and heritability. Proc. Fourth Int. Wheat Genetics Symp., Columbia, Mo. pp. 465-470.

Qualset, C. O., J. D. Prato, J. A. Rupert, H. E. Vogt, M. A. Khalifa, W. F. Lehman, and W. H. Isom. 1973. Anza - a new high-yielding, short-statured wheat variety. Calif. Agric. 27(2):14-15.

Qualset, C. O. and R. M. Granger. 1970. Frequency dependent stability of performance in oats. Crop Sci. 10:386-389.

Romero, C. A., and K. J. Frey. 1966. Mass selection for plant height in oat populations. Crop Sci. 6:283-287.

Sneep, J. 1977. Selection for yield in early generations of self-fertilizing crops. Euphytica 26:27-30.

Suneson, C. A., and F. N. Briggs. 1941. Wheat production in California. Calif. Agric. Exp. Sta. Bull. 659. 18 pp.

Suneson, C. A., W. K. Pope, N. F. Jensen, J. M. Poehlman, and G. S. Smith. 1963. Wheat Composite Cross I created for breeders everywhere. Crop Sci. 3:101-102.

Tee, T. S., and C. O. Qualset. 1975. Bulk populations in wheat breeding: comparison of single-seed descent and random bulk methods. Euphytica 24:393-405.

Thakare, R. B., and C. O. Qualset. 1978. Empirical evaluation of single-plant and family selection strategies in wheat. Crop Sci. 18:115-118.

Topeu, M. A. 1975. The inheritance of resistance to the barley yellow dwarf virus in wheat (Triticum aestivum L.). Ph.D. Dissertation. Univ. of California, Davis.

Williams, J. C., J. D. Prato, and M. D. Miller. 1964. New wheat variety introductions reduce stripe rust losses. Calif. Agri. 18(5):8-10.

THE GENETIC AND METHODIC BASES OF WHEAT BREEDING FOR HIGH AND STABLE YIELD IN OPTIMAL AND UNFAVORABLE PHYTOSANITARY CONDITIONS OF ENVIRONMENT

Edward Witkowski and Józef Bojarczuk
Poland

Abstract

The paper will consider: 1) the breeding of high and stable yielding varieties under typical Polish soil and climatic conditions, 2) the breeding of semi-dwarf and extremely intensive varieties for cultivation on very good soils or under irrigation, 3) the breeding of varieties less susceptible to eye spot and tolerant to the complex of phytosanitary soil conditions favorable for development of root and culm base diseases, and 4) methods of breeding and criteria for selection.

Evaluation of resistance to powdery mildew (Erysiphe graminis) and other diseases of leaves, resistance to eye spot, tolerance to unfavorable phytosanitary conditions of soil, winterhardiness, sprouting, quality, and breeding results will be discussed.

Poland occupies a central position among the countries of middle Europe. Its climatic conditions are differentiated. In its western part there is an influence of an Atlantic climate. In its eastern part the climate is rather continental with heavy frost and much snow. Therefore, the yielding stability of winter wheat depends in great degree on the winter-hardiness of varieties. The resistance of winter wheat to the basic fungous diseases contributes to yield stability, especially the leaf diseases (powdery mildew, Erysiphe graminis and brown rust, Puccinia recondita), ear diseases (Septoria nodorum and Fusarium sp.) and root rot and culm base diseases (Cercosporella herpotrichoides, Ophiobolus graminis, Fusarium sp. and Helminthosporium sp.).

Harvest mechanization creates the need to breed varieties resistant to lodging and sprouting.

Winter wheat is cultivated in Poland on loamy soils, mugwort and loessial soils and, to a small extent, on brown and fertile soils. In certain regions it is cultivated on degraded chernozem and black meadow soils. The cereals in Poland occupy 55-60% (7 million ha) of the total agricultural area. Winter wheat is produced on an acreage of 1.7 million ha. Therefore, it is sometimes cultivated in unfavorable phytosanitary field conditions after such forecrops as the cereals, alfalfa and clover.

The differentiated soil and climatic conditions create the necessity of breeding and growing various genotypes of high adaptability

Plant Breeding Institute and Experimental Station, Smolice

or special genotypes selectively accommodated to particular physiographic regions of the country.

The Plant Breeding Institute Experimental Station at Smolice has the following winter wheat program: a) develop high and stable yielding varieties suitable to production on typical winter wheat soil conditions and after favorable forecrops; b) breed semi-dwarf forms, appropriate for the best or irrigated soils; c) breed forms tolerant or less susceptible to root rot and culm base diseases suitable for cultivation after unfavorable forecrops. All these breeding programs are performed using the pedigree-bulk method.

The single mating crosses are obtained in glass-houses. By component evaluation we take into account the most important genetically based traits which ought to be accumulated in new varieties.

For adaptation to climatic and soil conditions of our country, including frost resistance and winter-hardiness, we use extensive Polish wheat varieties cultivated in the past (Wysokolitewka Sztywnosloma, Dankowska Biala, Plocka) east and north European varieties (Starke, Mironowska 808, Nadzieja, Jubilejna 50) and our own high yielding and winter-hardy strains. Such genotypes are used mainly as mother components.

Varieties and lines selected from our collection, lines developed within breeding and genetic research programmes as well as genotypes exchanged between Polish and foreign breeders are used as sources of resistance to the fungous diseases.

The breeding collections are maintained at 11 stations located in differentiated soil and climatic conditions in our country. The best results for getting forms resistant to powdery mildew have been obtained by the use of the following parent varieties: Maris Huntsman, strains from Hohenthurm and Zagreb, and the Swedish variety WW-153. Resistance to leaf rust is acquired similarly. The most commonly used resistant varieties are: INRA 81-12-3, German lines and the American variety Kalif 148.

In evaluation of parent varieties the resistance to stem and yellow rust is considered to be of secondary importance. The stem rust appears most frequently in the south-east regions of the country and it seldom has economic importance (in the case of epiphytotics only). The yellow rust appears in the west parts of Poland and has been of secondary importance in the past.

Resistance to eye spot has been obtained from the variety Cappelle or from varieties developed from Cappelle, from the interspecies hybrid VPM-1 and from its short straw mutation lines. In the last years the lines TVA, TVE and TVG were included in the crossing program. They have been selected at our station from the hybrid (*T. turgidum* x *Ae. ventricosa*) x *T. aestivum*. These lines combine low susceptibility to eye spot with resistance to powdery mildew and leaf rust.

Forms tolerant or less susceptible to the complex of root rot and culm base diseases are selected on the basis of special treatment. The varieties and breeding lines are planted in the soil taken from severely diseased wheat production fields.

The dwarf genes used in our program derive from crosses of our own materials with such forms as VT-54, Norin 10, Tom Thumb, and AMH. Lately we also have used the following materials: lines from Zagreb and Novi Sad, the English variety Maris Fundin and German lines from Hadmersleben.

The single mating hybrids (A x B) are not heavily selected because it is difficult to obtain recombinations involving several suitable traits. Therefore, they are used in a multiple crossing program of the following type: (A x B) x C, (A x B) x (A x C), and (A x B) x (C x D).

The F_2 populations are space-planted with an adjusted Pneumasem drill. This method of sowing has several advantages: small labor requirement, the possibility of using mechanical cultivation, the same conditions of growth and development, and the facility of individual plant selection. We believe in this stage of breeding the selection of traits depending on small numbers of dominant or recessive genes (for instance, resistance to leaf diseases caused by specialized obligatory pathogenes) is very efficient.

When the morphological traits are manifested and during the occurrence of the basic diseases, the individual plants are marked with colored tags. After harvest the individual plants are evaluated for grain plumpness.

The progenies of F_2 individual plants are tested using the standard method. They are sown with the seedmatic or a special device developed at the Petkus Breeding Station in East Germany. The spacing is approximately the same as in commercial production (450-500 kernels per 1 m^2).

Healthy F_3 progenies having the best phenotype are harvested and planted as bulks using the Pneumasem drill equipment again. At this stage of the breeding work the phenotypical correctness of plants and basic elements of yield structure are the main criteria of selection. The resistance of selected plants is considered, too. Some families of the F_3 generation also are planted in glasshouses to produce the F_4 generation.

After vernalization we plant the seed of the F_4 generation in the field. We use the generally known criterion of kernel selection. We do not lose the basic gene pool, and obtain 2 generations a year thereby accelerating the breeding cycle of the most valuable genotypes. The F_5 families are tested by the standard method in a microtrial with plot size of 1 m^2. Grana, the variety most widely produced in Poland, is used as a standard. The phenotypically uni-

form F_5 lines are harvested totally, and the seed is used to sow multiplication plots. Ear selection is practiced in the segregating forms.

In this breeding stage grain yield from the plot is the main criterion of selection. The F_6 and F_7 lines are planted in plots of 10 m^2, without replication with the standard. The best F_7 or F_8 lines are tested in breeding trials at two experimental stations. Simultaneously, these lines are reproduced in plots of 70 m^2 where negative selection is practiced.

The next stage of the work consists of yield trials conducted at 6 experimental stations and preliminary trials at 14 stations. The breeding cycle ends with the inclusion of the best lines in state trials supervised by The Research Center for Varieties of Agricultural Crops and to agrotechnical trials conducted by the Institute for Cultivation, Fertilization and Soil Science.

In the breeding program of semi-dwarf forms adapted to the best soils or irrigation, plants having straw length up to 75 cm are selected from populations of F_2 and F_4 generations. The semi-dwarf forms have a marked tendency to flower with open-glumes. Therefore, they are planted in special blocks to eliminate the possibility of crossing with normal straw forms.

The methods and technics applied in the breeding program of forms tolerant and resistant to the complex of root rot and culm base diseases differs only in some details from the breeding scheme discussed above. The initial materials and the breeding materials of different generations (from F_1 to F_7) are planted in a field with wheat as forecrop to intensify the potential of natural pathogenic agents. In autumn the plants are artificially inoculated with a population consisting of highly virulent strains of the fungus Cercosporella herpotrichoides.

The F_7 lines are reproduced in the normal breeding field after a suitable forecrop (pea, winter rape). These lines are also tested in a special microtrial with 4 replications in a breeding-infectious field. The yielding ability of F_8 lines is tested in normal breeding trials and in special trials. The special trials are sown with suitable standard varieties in the field after wheat as a forecrop.

The resistance of breeding materials to eye spot is evaluated using a glass-house resistance test of F_2 seedlings, F_4 bulks and F_7 and F_9 lines; and the evaluation of field culm affection of F_3 segregants and F_9 lines in the stage of waxy ripeness.

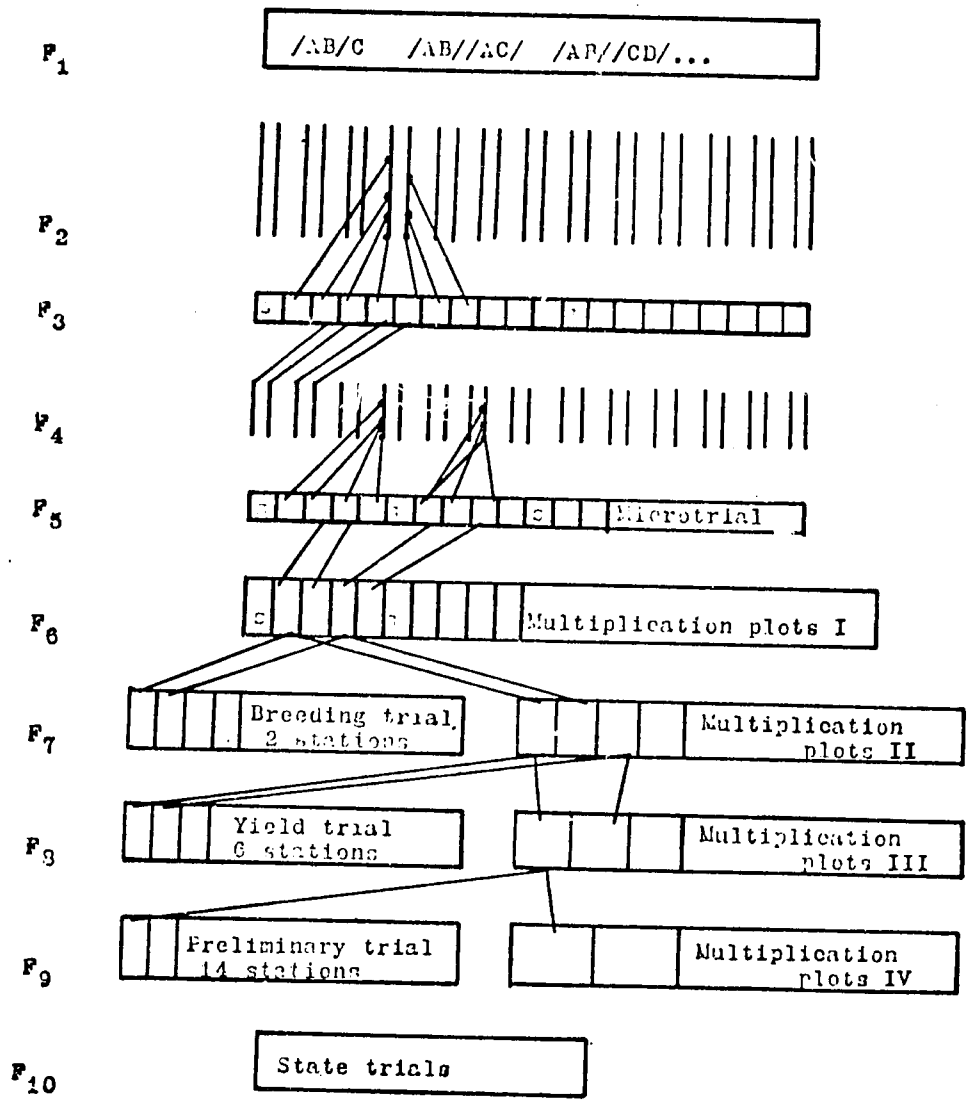
The evaluation of the general tolerance and resistance to the complex of root rot and culm base diseases is done in microtrials (F_6, F_7 lines), drill trials (F_8 lines) and special pot experiments (F_9). The valuable F_6 lines and all the F_7 lines and older generations are tested in some regions of the country in the observation

nurseries. Winter-hardiness and resistance to fungous diseases is evaluated there. Selected F_5 lines are tested in glass-houses for resistance to powdery mildew.

The partial or complex technological value of the breeding material is analyzed in the laboratories of the Institute. Resistance to low temperature of breeding materials (F_4 bulks, F_6 and F_7 lines) is tested in special freezing chambers. The same material is evaluated for sprouting in rain chambers.

The Plant Breeding Institute Experimental Station at Smolice maintains numerous contacts with other breeding stations and with Institutes and Academies of Agriculture in the country and abroad. This cooperation consists of ideas and materials exchange and sharing common experiments and research programs. The cooperation increases the effectiveness of the breeding work and accelerates breeding progress.

GENERAL SCHEME OF WINTER WHEAT BREEDING METHOD
PLANT BREEDING EXPIMENTAL STATION, SMOLICE



ECOBIOTIC ADAPTATION OF DIFFERENT GENOTYPES OF WINTER WHEAT ASSOCIATED WITH BREEDING

Josip Potocanac and Rade Mlinar
Yugoslavia

Abstract

The relationship between wheat genotypes and environment including level of technology, has been thoroughly investigated. The problem also was discussed at the 1st and 2nd International Winter Wheat Conferences. Adaptability of wheat may be increased using new genetic and technological accomplishments. At the same time, analysis of adaptability provides information about distribution of wheat varieties to the most suitable climatic regions. On the basis of our breeding work and investigations, we will discuss our contribution to the solution of the problem of ecobiotic adaptation in general and especially relating to adaptability of high-yielding, semi-dwarf genotypes of winter wheat under conditions of intensive production in Eastern Europe.

- - - - - -

Introduction

Genotype - its characters in general - and particularly those traits associated with yielding capacity, adaptability to particular environment and technology level, has the dominant influence upon yield and stability in wheat production (MacKey 1962 and 1968; Potocanac, 1962 and 1975; and others).

Therefore, problems of both yielding capacity and adaptability of genotype, separately and in combination, have been subjects of many analyses and investigations (Finlay, 1963 and 1968; Bell, 1972; Borojevic, 1971; and others).

Also, results obtained in the International Winter Wheat Performance Nursery were used to obtain data about wheat types and genotypic characters which should be considered in breeding. (Bell, 1972; Schmidt, Johnson and Stroike, 1972; Borojevic, 1972 and 1975; Jensen, 1975; and others).

The goal of most breeders is to connect yielding capacity with general adaptability. Many authors have pointed out a number of problems relating to this which have not been investigated. For example, Finlay (1968) ascertains that a particular wheat type (model) is of secondary importance concerning yield and adaptability because all of the genotypic traits associated with yield and general adaptability have not yet been found. He also thinks that breeding for a particular plant type narrows genetic variability and leads to a decline in breeding progress. From another side, many breeders (Strampelli, 1932; Borlaug, 1965; Briggle and Vogel, 1967; Potocanac, 1956; Borojevic-Potocanac, 1966; Bell, 1972; and others) have indicated the necessity

Institute for Breeding and Production of Field Crops, Zagreb

of changing the morphological wheat type (model). They have reduced the size of vegetative plant parts, e.g. shortened plant height. They have developed semi-dwarf wheat types with more grain, improved harvest index and increased lodging resistance. This has resulted in increased grain yield per unit surface area and in superior resistance to lodging, which is a limiting factor in intensive, modern production. Thus, in some regions higher yields and greater stability of production have been attained.

Experiments concerning both yielding capacity and adaptability are continuing not only to study this relationship in general, but also to study those relations using the new wheat genotypes in the changed technological conditions of today.

Objective of Investigation

In the IWWPN trial with divergent climatic-environmental and technological conditions of production, genotypes with various morpho-physiological characters were tested. These characters include semi-dwarf, high-yielding, early winter wheat genotypes. From annual reports by Johnson and co-workers abundant data are obtained concerning yield, varieties, and individual characters. Correlations between individual characters and yield at each test site and over all sites are available.

Obviously, estimation of yielding capacity and adaptability of one morpho-physiological wheat type is to be made on the basis of the average for all localities. Data also indicate that it may be even more important to evaluate cultivar yielding capacity and adaptability in particular environments, including technology levels, as well. If performance estimates are based only on the average of all sites, a wrong conclusion might be made about the yield potential and adaptability of cultivars for specific regions of production. For example, the following yield rankings were obtained for some of the cultivars in the IWWPN in 1974 (Table 1).

From the data one can see that both average yield and yield ranking of cultivars at sites of northern and southern Europe are different in comparison values from all sites.

In the same year the simple correlation coefficients, over all sites, between (1) yield and plant height were positive at 28 sites and negative at 15 sites; (2) yield and length of vegetative growth (till flowering) were positive at 15 localities, and negative at 29 localities. Similar variability in cultivar yield ranking and correlation coefficients was found in other years.

Taking this into consideration, we were interested in performance of two types of winter wheat in the region of middle and southeastern Europe (territory from 43-48° north latitude, from Krasnodar at the east to Zurich at the west. Sites in this region which were similar in technology levels and climatic conditions during wheat vegetation were selected. The following

Table 1. SUMMARY OF YIELD RANKINGS FOR CULTIVARS IN THE 6th IWWPN-1974.

For all sites	For sites in North.Europe	For sites in South.Europe
Kavkaz (42.2 q/ha)	Maris Nimrod (73.6 q/ha)	Zlatna Dolina (58.1 q/ha)
Aurora (42.0 q/ha)	Caribo (68.6 q/ha)	Kavkaz (58.0 q/ha)
Burgas 2 (40.3 q/ha)	Clarion (64.1 q/ha)	Sanja (55.7 q/ha)
Bezostaja 1 (40.2 q/ha)	Kavkaz (63.9 q/ha)	Rousalka (55.1 q/ha)
Maris Nimrod (39.9 q/ha)	Aurora (63.0 q/ha)	Aurora (54.9 q/ha)
Blueboy (39.8 q/ha)	Manella (61.8 q/ha)	Demar 4 (53.6 q/ha)

two winter wheat types were observed: (1) semi-dwarf, early maturing winter wheats, either possessing or not possessing resistance to P. graminis, E. graminis, etc., such as : Zlatna Dolina, Talent, Sanja, Yubiley, Zlatoklasa (Zg. 4364/73), and others, and (2) tall types with plant height above 90 cm, in view of vegetation, late-maturing, such as: Bezostaja 1, Atlas 66, Probstdorfer Karat, Jubilar, and similar ones.

Yielding capacity and adaptability of the two wheat types mentioned were estimated on the basis of: (1) determination and comparison of the realized average grain yield/ha, average plant heights and average length of vegetative period and (2) calculation of correlation coefficients between grain yield/ha and average plant height, and grain yield/ha and average length of vegetative growth (from January 1 - flowering).

Investigation and analyses were done on cultivars in the IWWPN at Zagreb during 4 years and from 10 locations of the region mentioned during 3 years.

Results and Analyses

Semi-dwarf, early winter wheats are compared with tall, late types when grown at Zagreb in 1978 (Figure 1). Average grain yield of the semi-dwarf types was 48.62 q/ha in relation to the average of 24.25 q/ha for the tall and late types. The difference in yield was 24.37 q/ha. The average plant height of the semi-dwarf wheats was 79.0 cm compared with the average of 99.0 cm for tall and late types. The average number of days from January 1 till flowering was 149 days, in comparison with 154 days for late wheats.

In 1977 (Figure 2) the mean values for the two wheat types from the IWWPN at Zagreb were as follows: average yields of 53.03 and 40.26 q/ha for the semi-dwarf, early varietes and tall, late varieties respectively; mean plant heights of 76.0 cm and 107.0 cm along with vegetative periods measured from January 1 of 137 days and 142 days for the two respective wheat types.

The early-short types had a yield advantage of 12.77 q/ha, were 31.0 cm shorter, and matured an average of 5 days sooner than the tall-late varieties.

In the same experimental year the mean values from 10 IWWPN sites of the region mentioned, were as follows: average yield of semi-dwarf, early varieties was 62.98 q/ha, while average yield of tall, late types was 52.16 q/ha; average plant height of the first type was 72.0 cm, of the second type 106.0 cm. Length of the vegetative period measured from January 1 was 136 days, and 143 days, respectively. Thus, the early, semi-dwarf varieties yielded 10.82 q/ha more grain, were 34.0 cm shorter, and flowered an average of 7 days sooner than the late, tall varieties. The same relations between semi-dwarf, early genotypes and tall, late ones were found in 1975, and 1974 (Figures 3 and 4).

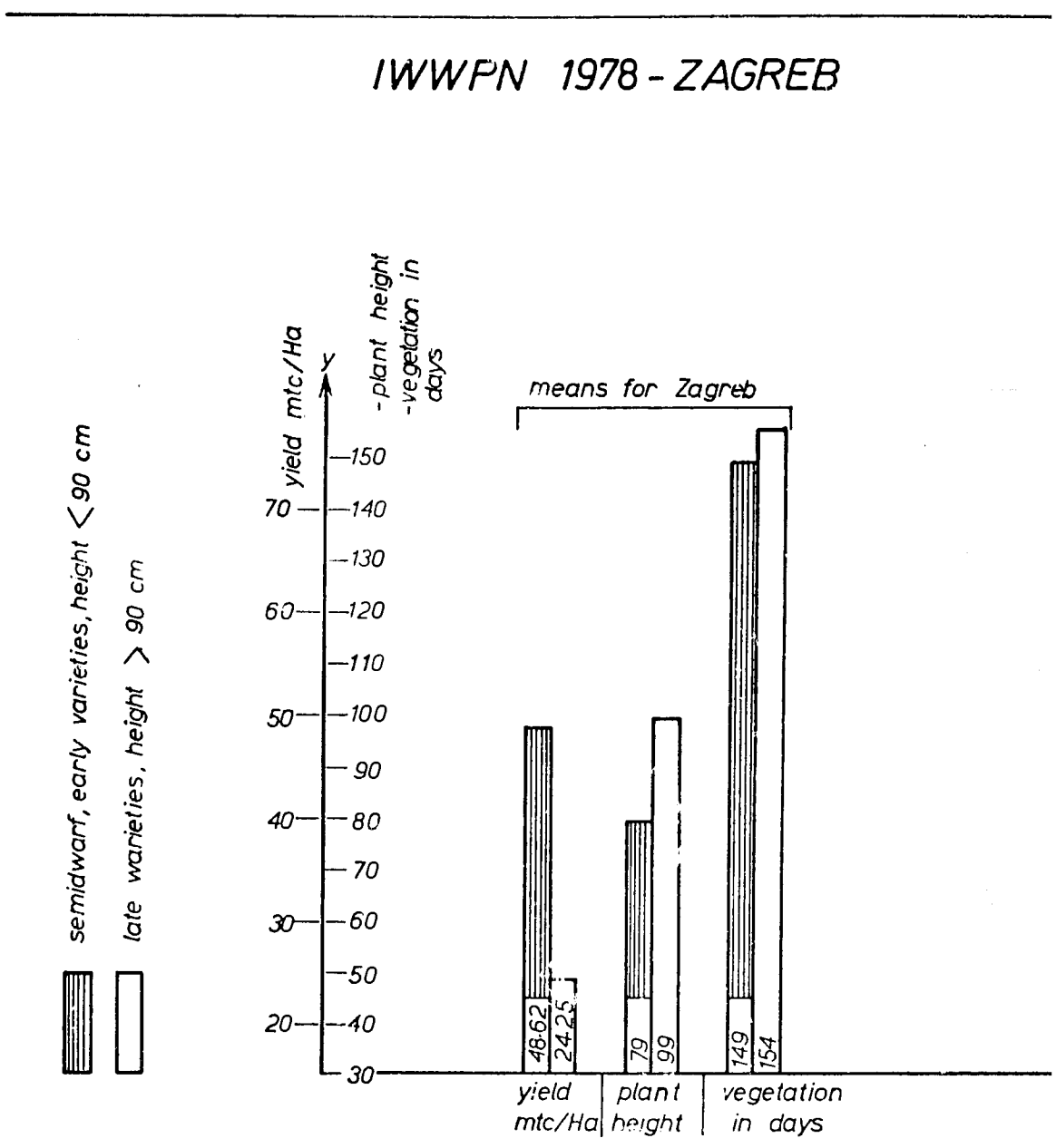

IWWPN 1978 - ZAGREB
semidwarf, early varieties, height < 90 cm
late varieties, height > 90 cm
yield mtc/Ha
y
- plant height
- vegetation in days
means for Zagreb
70
60
50
40
30
20
150
140
130
120
110
100
90
80
70
60
50
40
30
48·62
24·25
79
99
149
154
yield mtc/Ha
plant height
vegetation in days

Figure 1

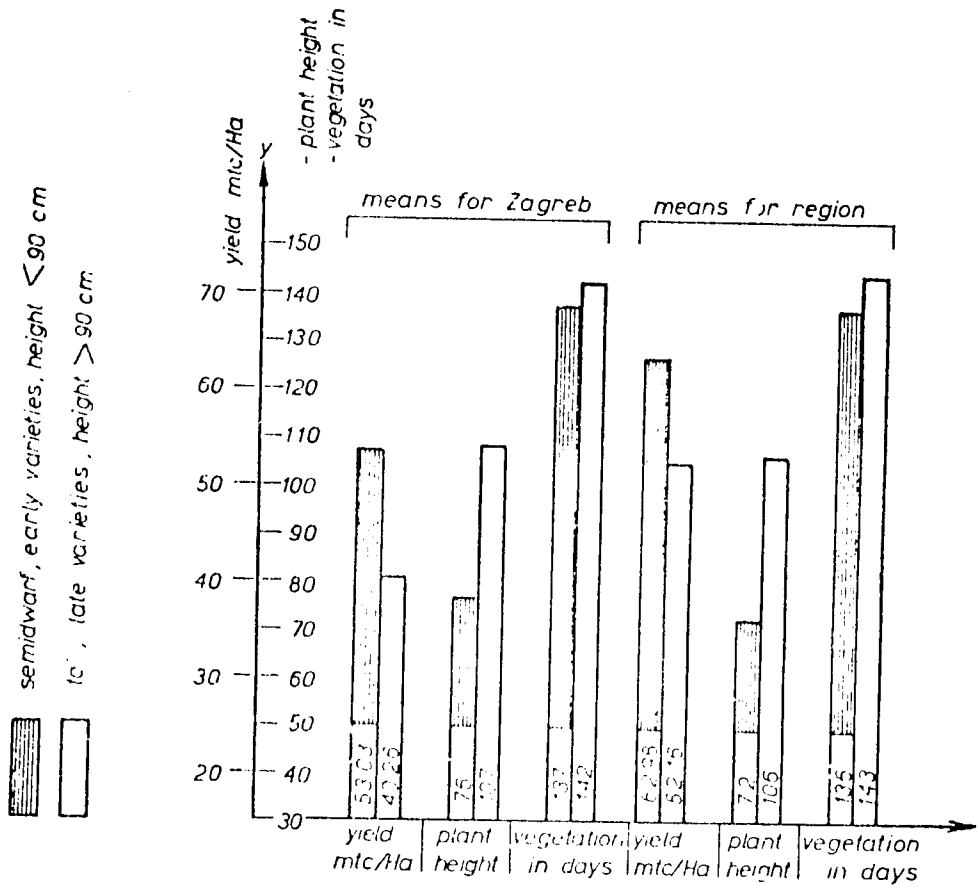

IWWPN - 1977
semidwarf, early varieties, height < 90 cm
late varieties, height > 90 cm
yield mtc/Ha
- plant height
- vegetation in days
means for Zagreb
means for region
yield mtc/Ha
plant height
vegetation in days
yield mtc/Ha
plant height
vegetation in days

Figure 2

IWWPN - 1975

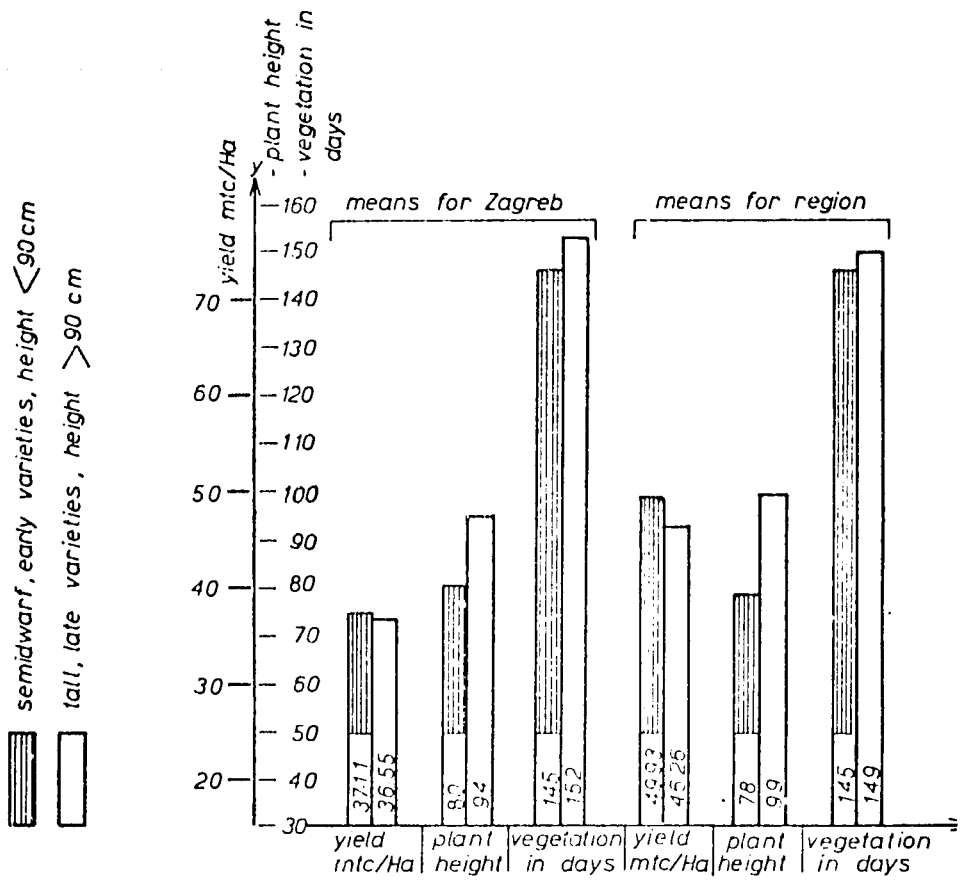


Figure 3

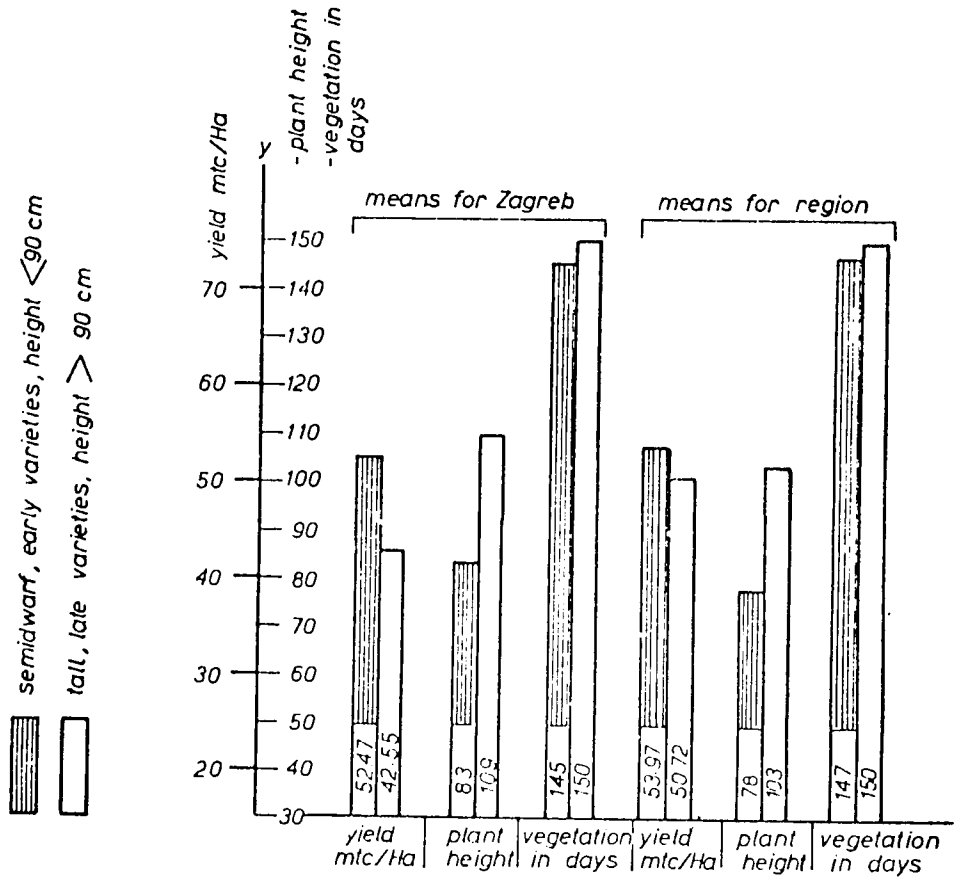

IWWPN - 1974
semidwarf, early varieties, height <90 cm
tall, late varieties, height > 90 cm
yield mtc/Ha
y
- plant height
- vegetation in days
means for Zagreb
means for region
70
60
50
40
30
20
150
140
130
120
110
100
90
80
70
60
50
40
30
52.47
42.55
83
109
145
150
53.97
50.72
78
103
147
150
yield mtc/Ha
plant height
vegetation in days
yield mtc/Ha
plant height
vegetation in days

Figure 4

How the effects of plant height and length of vegetation of these two types of wheat are reflected in yield, can best be seen from the correlation coefficients between yield, plant height, and length of vegetation.

Table 2 shows statistically significant negative correlations between yield and characters indicated in 1978 for Zagreb, and in 1977 both for Zagreb and the whole region, while in 1975 and 1974 correlations between yield and plant height, and yield and length of vegetation showed non-significant negative coefficients.

Values of the correlation coefficients between yield and the two characters indicate that plant height and length of vegetation are two of the main reasons for the differences in yield between semi-dwarf, early and tall, late wheat genotypes.

Thus, it might be concluded that in this region genotypes of shorter plant height (semi-dwarf) and early-maturing are better adapted to climatic-environmental conditions and technology level than tall and late genotypes. According to our analysis of results, lower yield of tall and late genotypes is caused by lodging of tall genotypes, and prematurity of late genotypes.

Lines of regression for correlations between yield-plant height and length of vegetation for Zagreb are presented in Figures 5, 6, 7, and 8.

It can be seen from the Figures that negative regression was more pronounced between plant height and yield in comparison with length of vegetation and yield. Similar results are seen for the regression lines computed.

Conclusion

Yield, plant height and length of vegetation, data from the IWWPN at Zagreb and at sites with similar technology levels in the region of middle and southeastern Europe (territory from 43-48° north latitude, from Krasnodar at the east to Zurich at the west) indicate that semi-dwarf, early winter wheat cultivars performed better than the tall, late types at Zagreb and at 10 sites in the region in 1977, 1975, and 1974.

Thus, it might be concluded that semi-dwarf, early genotypes in the climatic-environmental region mentioned, including also technology level in that region, from the point of view of production, surpass in yield and adaptability the tall, late genotypes. Therefore, breeding preference should be given to this morphophysiological type of winter wheat in Yugoslavia and surrounding regions.

Table 2.

SIMPLE COEFFICIENTS OF CORRELATION BETWEEN YIELD / HEIGHT OF PLANT AND YIELD/VEGETATION IN IWWPN FOR YEARS 1978, 1977, 1975 AND 1974

Location	YEARS	1978		1977		1975		1974	
	Correlations between	R	N	R	N	R	N	R	N
Zagreb	Yield and - plant height - vegetation (1.Jan.-flowering)	 - 0.8834 ++ - -0.6438 ++	14	 - 0.6121 ++ -0.8195 ++	19	 - 0.2810 - 0.2839	15	 - 0.3950 - 0.2393	15
Region	Yield and - plant height - vegetation (1.Jan.-flowering)	 - -		 -0.7262 ++ -0.6601 ++	19	 -0.2643 - 0.3644	15	 -0.3609 -0.2961	15

++ = significant

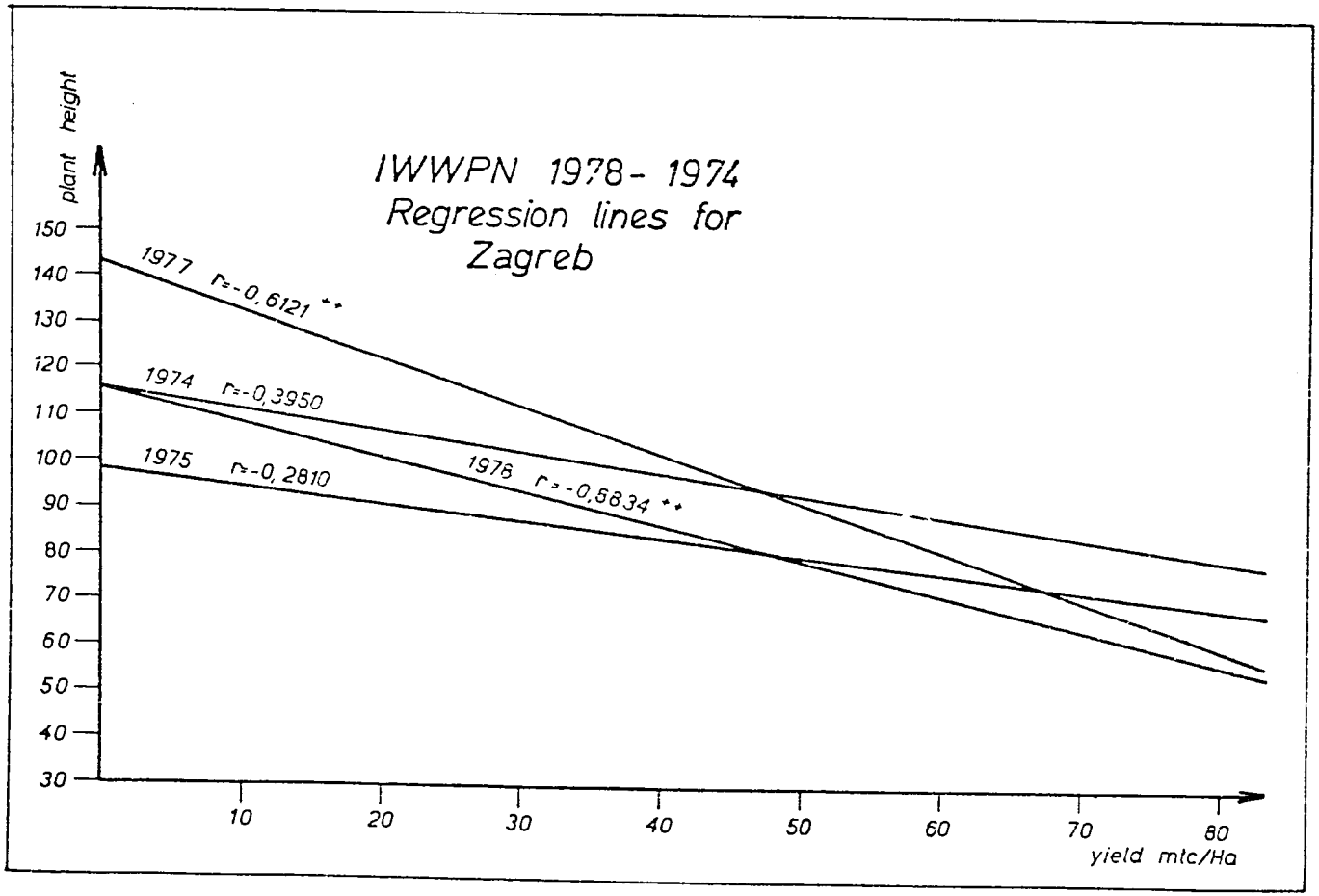

IWWPN 1978 - 1974
Regression lines for
Zagreb
plant height
150
140
130
120
110
100
90
80
70
60
50
40
30
1977 r=-0,6121 **
1974 r=-0,3950
1975 r=-0,2810
1976 r=-0,5834 **
10
20
30
40
50
60
70
80
yield mtc/Ha

Figure 5

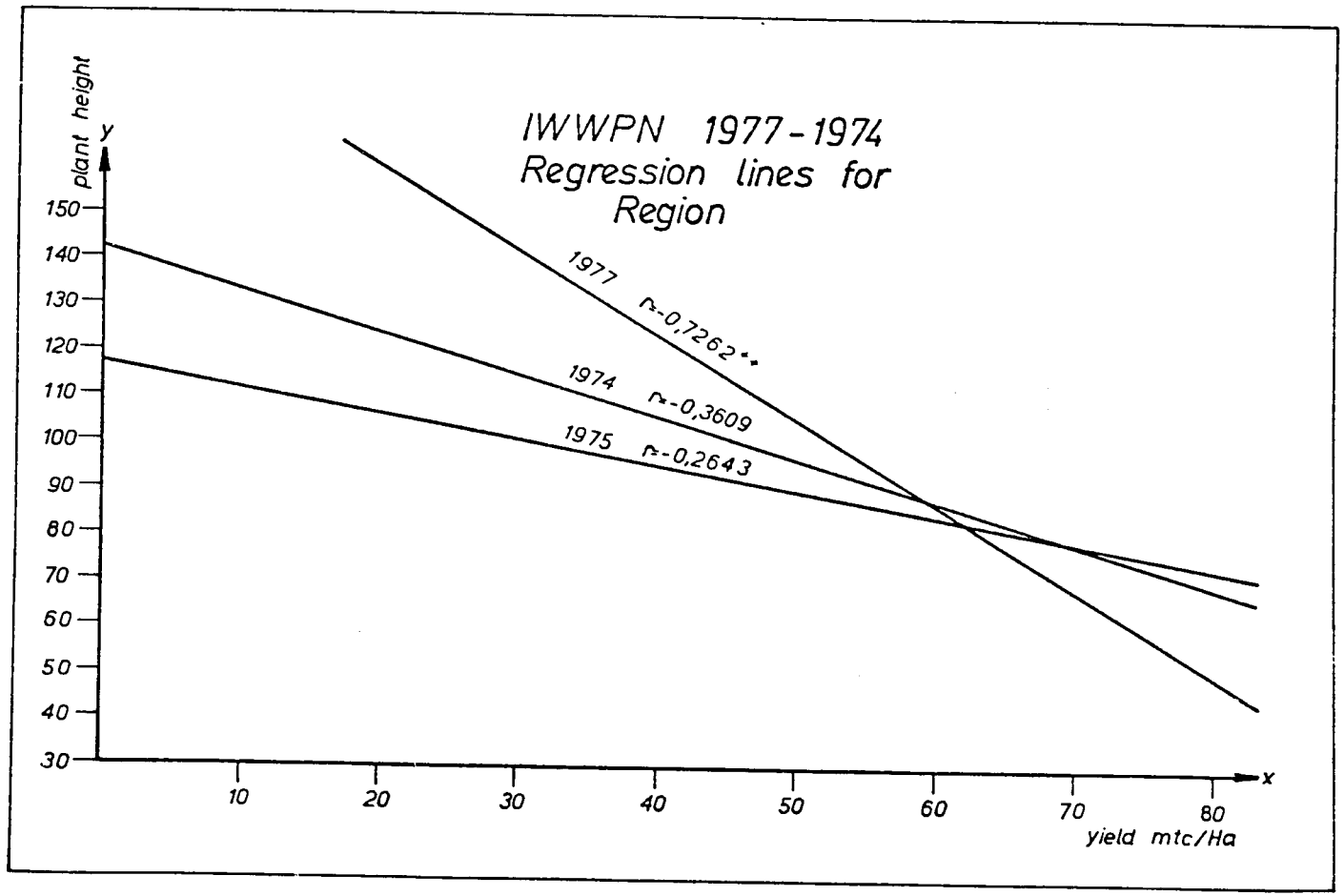

IWWPN 1977-1974
Regression lines for
Region
plant height
y
150
140
130
120
110
100
90
80
70
60
50
40
30
1977 r=-0,7262**
1974 r=-0,3609
1975 r=-0,2643
10
20
30
40
50
60
70
80
x
yield mtc/Ha

Figure 6

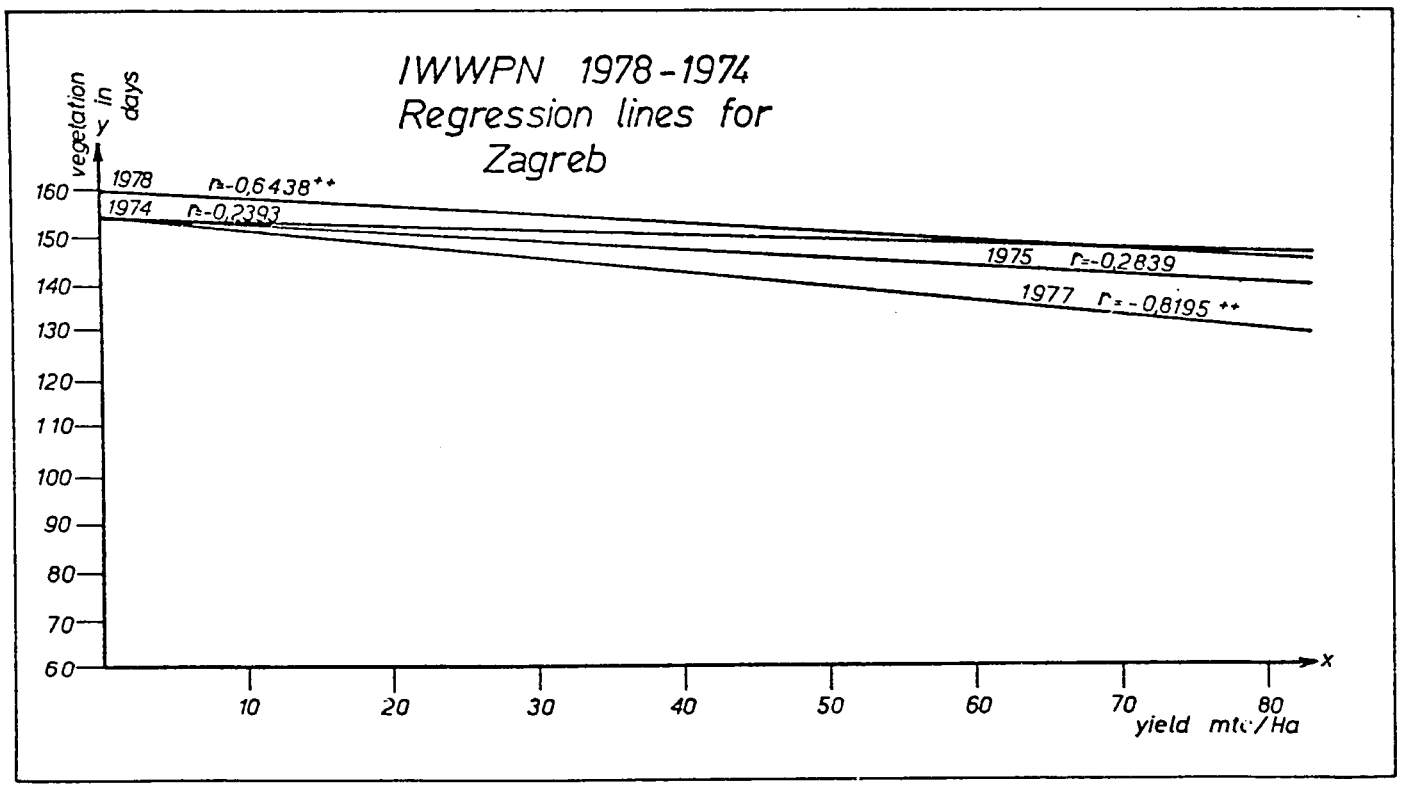

IWWPN 1978-1974
Regression lines for
Zagreb
vegetation
y in
days
1978
r=-0,6438++
1974
r=-0,2393
1975
r=-0,2839
1977
r=-0,8195++
160
150
140
130
120
110
100
90
80
70
60
10
20
30
40
50
60
70
80
x
yield mt/Ha

Figure 7

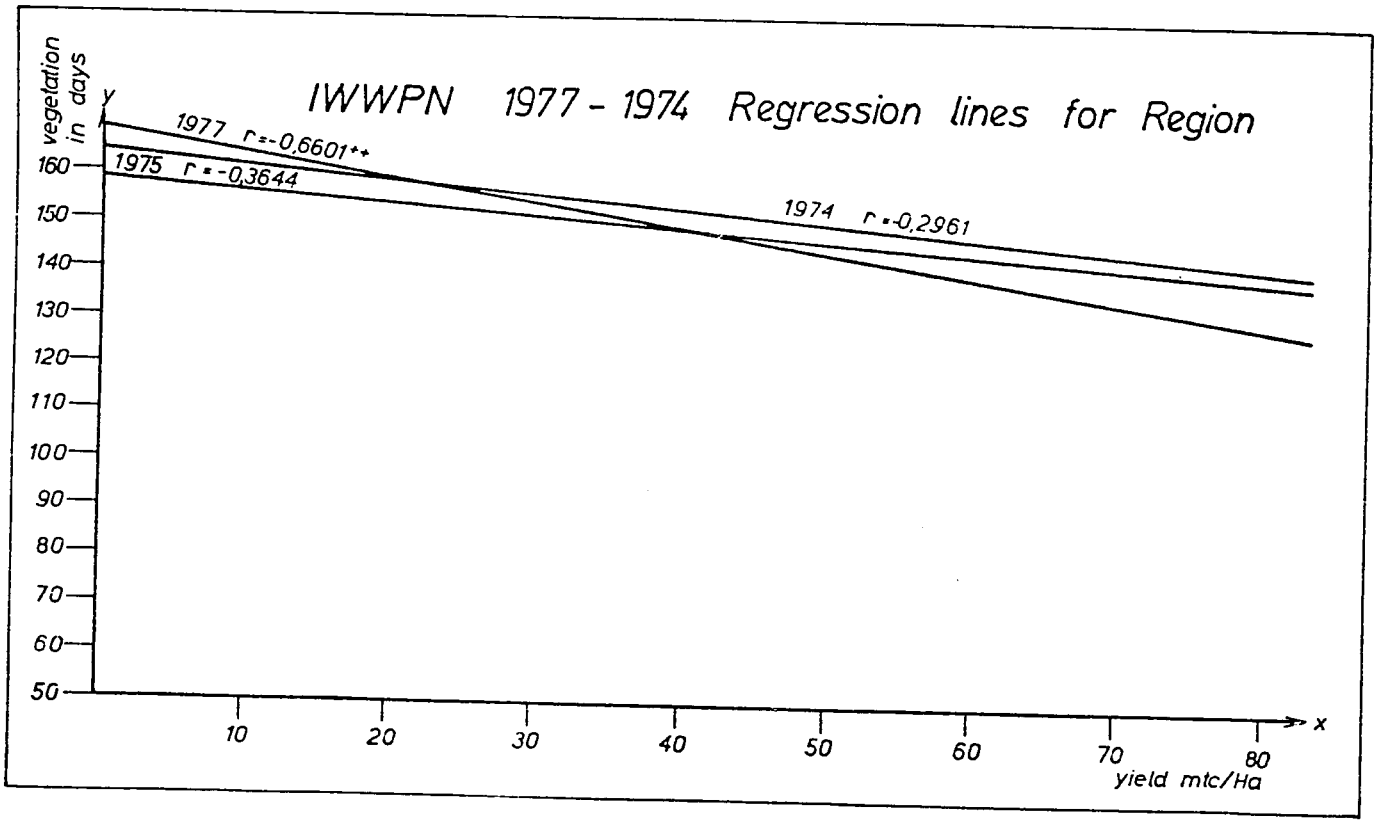

IWWPN 1977 - 1974 Regression lines for Region
vegetation in days
y
160
150
140
130
120
110
100
90
80
70
60
50
1977 r=-0,6601++
1975 r=-0,3644
1974 r=-0,2961
10
20
30
40
50
60
70
80
x
yield mtc/Ha

Figure 8

References

1. Bell, G.D.H. 1972. Specific adaptation in winter wheat. Proceedings IWWC.Ankara.
2. Borojevic, S. and J. Potocanac. 1966. The development of the Yugoslav program for creating high-yielding wheat varieties. Proceedings of 5th Yugoslav Symposium on Research in Wheat. Novi Sad.
3. Borojevic, S. 1972. Limiting factors in wheat adaptation. Proceedings IWWC. Ankara.
4. Finlay, K.W. 1968. The significance of adaptation in wheat breeding. Proceedings of the 3rd Int. Wheat Genetics Symposium. Canberra.
5. Briggle, L.W. and O.A. Vogel. 1968. Breeding short stature, disease resistant wheats in the USA. Euphytica 107-130. Wageningen.
6. Borlaug, N.E. 1968. Wheat breeding and its impact on world food supply. Proceedings of the 3rd Int. Wheat Genetics Symposium. Canberra.
7. Jensen, N.F. 1975. Breeding stratigies for winter wheat improvement. Proceedings of 2nd IWWC, Zagreb.
8. Kuhr, S.L. et. al., 1979: Results of the ninth Int. Winter Wheat Performance Nursery Grown in 1977. Inst. of Agri., Univ. of Nebr., Lincoln.
9. Kuhr,S.L. et. al. 1979. Preliminary report of the tenth Int. Winter Wheat Performance Nursery Grown in 1978. Inst. of Agri., Univ. of Nebr., Lincoln.
10. MacKey, J. 1966. The wheat plant as a model in adaptation to high productivity in different environments. Proceedings of the 5th Yugoslav Symposium of Research in Wheat. Novi Sad.
11. Potocanac, J. 1956. Problem sorte psenice kod nas. (Problem of wheat variety in our country). Agron. glasnik, Zagreb.
12. Potocanac, J. 1956. Nekoliko rijeci o nerodici, sortama i selekciji psenice. (A few words about failure of wheat crop, wheat varieties and wheat breeding). Agron. glasnik, Zagreb.
13. Potocanac, J. 1962. Rezultati istrazivanja kompleksa priroda kod psenice. (Results of studies of yield complex in wheat). Agron. glasnik, Zagreb.
14. Potocanac, J. 1975. Effect of wheat breeding on wheat production in Yugoslavia.Proceedings of 2nd IWWC. Zagreb.
15. Wilhelmi, K. D. et. al. 1976. Results of the sixth Int. Winter Wheat Performance Nursery Grown in 1974. Inst. of Agri., Univ. of Nebr., Lincoln.
16. Wilhelmi, K. D. et. al. 1977. Results of the seventh Int. Winter Wheat Performance Nursery Grown in 1975. Inst. of Agri., Univ. of Nebr., Lincoln.

FULL-DWARF X SEMI-DWARF HYBRID WHEATS

James A. Wilson, Jerry A. Wilson and
Herbert J. Schmidt
United States

Abstract

The dwarfing genes Rht1 and Rht2, have been employed widely in the development of improved semi-dwarf wheats. In some cases, both genes have been used for breeding full-dwarf varieties. In developing semi-dwarf lines it is highly likely that some of the best genetic combinations for vigor result in too much height and eventual discard. On the other hand, selection at the full-dwarf level allows for efficient visual selection for vigor and disease resistance, but the line may not be usable because it is still too short for its environment. One solution to these problems appears to be through making full-dwarf x semi-dwarf hybrids. In doing this, the hybrid cultivars are likely to manifest the maximum in vigor and yield while maintaining optimum height. Control of height in single cross hybrids has been difficult to manage but with the use of 3 dwarfing genes, involving two loci, the problem is minimized.

Measurements were made on full-dwarf x semi-dwarf hybrids and seed set on male-sterile full-dwarf females at Wichita, Kansas, in 1979. Ten hand-crossed hybrids were made earlier by crossing two full-dwarf females (Rht1, Rht2) with five semi-dwarf males (Rht2). The single crosses of these matings were all heterozygous for Rht1. The two parents and the hybrid of each mating were grown in observation plots with the hybrid plot between the two parental plots. In comparing the means of the parents with the hybrids in individual measurements, it was found that the hybrids were consistently shorter than the taller semi-dwarf parent and higher in yield. In overall mean values, the hybrids showed higher head number per plot and test weight. A total of seven field pollinations were obtained on the two full-dwarf steriles with six different males. Seed yields on full-dwarf steriles in hybrid crossing blocks were similar in yield to the pollinator line which seems to indicate that they can be successfully used as seed parents for hybrids.

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The use of the dwarfing genes, Rht1 and Rht2 in developing wheats with improved plant type and yield has become a common practice in many areas of the world. These two dwarfing genes normally have been employed through fixation in pure lines. Where both are fixed the line is often referred to as being a full-dwarf, but where only one of the dwarfing genes is present it is called a semi-dwarf. A height class not previously possible in line breeding can now be made available through hybrid seed production that utilizes a cytosterile full-dwarf female line and a pollen-restoring semi-dwarf male line or the reciprocal relative to the dwarf character.

Contribution by DeKalb Hybrid Wheat, Inc., Wichita, Kansas

Materials and Methods

The full-dwarf x semi-dwarf hybrids studied in these observtions were made by emasculating two full-dwarf females and pollinating with five different males that were homozygous for Rht2. Parents and the hybrid of each mating were planted in four-row observation plots, using the same number of seed in each of the three plots. The seeding rate between the sets of three varied from around one half to equal that of commercial wheat fields. All plots were 1.22 m in width and 2.44 m in length. Overall mean values in the comparative measurements were based on 10 plots each of hybrids, female parents and male parents. Grain weight/head was determined by taking 25 head samples from each plot. Head number per plot was estimated by dividing harvest plot weight by head grain weight.

Male sterile counterparts with Timopheevi cytoplasm of the two females used in the hybrid studies were also planted in six field crossing blocks involving six different pollen-restoring lines. Five males were mated with only one female and one male was mated with both. The two females occupied only a small portion of the female area of the blocks. They were mainly planted in 1.22 x 2.44 m plots. The female to male area of the crossing blocks was on a 1:1 ratio. The overall dimensions of the crossing block was around 60 x 120 m. Extra male was planted across the east and west ends of the blocks to help isolate the females in the inner strip area of the blocks. Presumably, the majority of the pollen for seed set came from the male in the interplanted female-male strips.

Observation data from the hybrid-parent comparisons and seed yield on male-sterile full-dwarf female lines were from plots grown at Wichita, Kansas during the 1979 harvest year.

Results and Discussion

An array of data was taken to characterize the full-dwarf x semi-dwarf hybrids and to study the plant characteristics that appeared to be affecting grain yield. Comparative hybrid and parent data are given in Table 1.

A comparison of the heading date reveals that the hybrids are close to the early parent in heading. This observation agrees with our past findings, although occasionally hybrids can be earlier than either parent when the parents are quite close in heading. As the heading date widens between the two parents the hybrid tends to be increasingly later than the early parent.

Table 1. Overall mean values of full-dwarf x semi-dwarf hybrids compared with their parents.

Character	Females	Hybrids	Males
May heading	8.7	9.0	11.0
Height - cm	68	82	91
Yield - kg/ha	5326	6241	5010
Heads per plot	1390	1635	1384
Head weight - gm	1.16	1.14	1.08
MKW - gm	32.7	33.4	30.2

The height of the hybrids was nearly intermediate between the full-dwarf and semi-dwarf parents. High heterotic effects might be expected to make the hybrid considerably taller than the midparent height unless some component of yield is increased significantly which appeared to be the case in these analyses. Height is one expression of vigor which may lead to unfavorable straw:grain ratios and less than optimum grain yield. By manipulating the dwarfing genes in two parent forms, it may be possible to utilize vigourous combinations that might not be useable in a pure line form. Selection of tall full-dwarfs gives increased efficiency in visual selection for vigor and disease resistance, but the resulting line is generally still too short for broad adaptation. On the other hand, the most vigorous semi-dwarf lines that should be saved are often set aside as being too tall and having unfavorable straw:grain ratios. Control of height and utilization of line vigor and hybrid vigor seems most possible wit the full-dwarf x semi-dwarf hybrids. This is one of the approache that has been followed for many years in our hybrid breeding program. Any genetic screening system which enables the breeder to select for vigorous combinations, whether through inbreeding or some other system that aids in the expression of vigorous genetic combinations, is valuable for genetic improvement provided the adversity is eliminated in the hybrid.

The expression of mean yield in the hybrids was 17% above the mean yield of the female parents and 25% above that of the males (Table 1). The hybrid had a good margin of superiority in most of the 10 comparisons given in Table 2. Yield in the hybrids was strongly influenced by head number which was 17.6% greater than the female parents. Head weight was slightly less in the hybrids compared to the female parents, reflecting the fact that as head number increased the head grain weight was diminished. Possibly nutrients played a role in preventing the hybrid from equaling the better parent in head grain weight. Though head weight was slight ly less than the better parent the difference was not of sufficient magnitude to offset the positive effect for yield expressed in head number. Kernel weight was slightly in favor of the hybrids which probably contributed to the hybrid's superior yield performance.

Since the hybrids had a diffenent height expression than the parents, conclusions on heterosis cannot be made. The hybrid's height could have been more optimum for grain yield than that present in the parents. In many hybrid combinations, plant type and adaptation diminish, enhance or mask heterotic effects. Consequently, genetic background must be considered in estimating heterotic effects.

The data (Table 3) obtained on seed yields on two full-dwarf steriles in 1979 suggest that they can be successfully used as seed parents in hybrid seed production. The mean yield of both females in the Wichita, Kansas crossing blocks in all seven observations was 3961 kg/ha, while that of the male pollinators was 3887 kg/ha. Wind pollination conditions at Wichita in 1979 were very good with some male-sterile lines approaching normal seed set. Although percent seed set was not determined on the full-dwarf steriles of this study, seed set was likely 90% or better.

Table 2. Yield performance of hybrids and their parents.

Set*	Kind	Yield kg/ha	% Hybrid Superiority	Set*	Kind	Yield kg/ha	% Hybrid Superiority
1	380	4863	8	6	397	5468	4
	F1	5246			F1	5697	
	159	3948	33		159	4520	26
2	380	5361	2	7	397	5657	13
	F1	5478			F1	6403	
	210	4503	22		210	4997	28
3	380	5485	11	8	397	4762	33
	F1	6100			F1	6319	
	305	5488	11		305	4742	33
4	380	5203	32	9	397	5788	21
	F1	6881			F1	7012	
	213	5670	21		213	4728	48
5	380	5303	20	10	397	5411	28
	F1	6340			F1	6945	
	362	5391	18		362	6148	13

* Normal seeding rate for each entry in set 9.
1, 2, 4, 6, 10 - .67 to .89 of normal rate.
3, 5, 7, 8, - .41 to .55 of normal rate.

Table 3. Yield of six semi-dwarf males and two full-dwarf male sterile females in hybrid crossing blocks at Wichita, Kansas, 1979.

Kind	Mean Yield kg/ha	Yield Range kg/ha
Six Males	3887	3087 - 4359
Two Females	3961	1950 - 5824

Soil borne mosaic virus in some cases adversely affected male yield but both females were resistant. Some low yield estimates on the females were due either to poor emergence or some winter damage. The greatest handicap to the use of full-dwarf steriles as seed parents under Kansas conditions may be the problems associated with poor emergence from dry soil conditions or soil crusting after heavy rains.

Most full-dwarfs have smaller anthers and less extrusion than taller types. Considerable selection effort is required to identify types that have normal anthers. Stigma development and ability to receive pollen is generally similar to that in the semi-dwarfs. Since the pollen shedding character is generally below normal some difficulty is expected in increasing full-dwarf steriles unless the foundation female seed fields are planted at high yield sites. Pollen production is expected to increase on the full-dwarf maintainer males as the grain yield potential increases which should result in higher seed set on the female.

Summary and Hypotheses

Preliminary information on full-dwarf x semi-dwarf hybrid performance indicates that hybrids of this nature will be intermediate in height and have higher yield potential at some sites than either full-dwarf or semi-dwarf pure lines. Control of height in hybrid breeding has been difficult in the past and this approach appears to minimize the problem. Visual selection for vigor at the inbred level may be more efficient and utilizable through combining full-dwarf and semi-dwarf lines into hybrids. Use of full-dwarf females as seed parents in hybrid production appears possible with proper management. Some problems may be encountered in the process of increasing full-dwarf steriles for use as seed parents.

THE COMPUTER - AN AGRONOMIST'S ASSISTANT

N. H. Scott and W. E. Kronstad
United States

Abstract

Space age technology has made possible many innovative advances in electronic data processing equipment and the computer has become a valuable assistant to the agronomist.

As a clerical assistant, the computer can relieve the agronomist of such tedious chores as record-keeping and list-making. Computer software was developed to update and print pedigree lists for field books, pedigree tags for field identification and labels to be used on harvest sacks. Pedigrees of new crosses are generated from source numbers of parental lines and numbers of selections made in each population are recorded for future use. Transcription errors are greatly reduced and pedigrees are standardized to facilitate computer searches for various parental sources.

Miniaturization and improved electronic circuitry have made the computer available as a field assistant. A fast method of weighing grain samples and analyzing yield data immediately in the field was devised. Analysis of harvest data is instantaneous and decisions can be made in the field as to what material should be advanced for further testing.

When the analytical and memory capabilities of the computer are harnessed, it becomes a valuable research assistant. In the summarization of data of the International Winter x Spring Wheat Screening Nursery, over 250,000 bits of information contributed from approximately 100 locations are sorted, catalogued and summarized. The cooperator then has information available to him before his next crossing season describing the adaptability, disease resistance and yield potential of the 250 lines comprising the screening nursery. The computer is also used for data storage and retrieval. Information concerning the agronomic performance of advanced lines is stored so that a catalog of that information over several years can be retrieved and used in identifying promising new lines and parental sources.

The agronomist can realize increased accuracy and efficiency when the computer is utilized effectively as an assistant rather than the dictator of research goals.

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In the last ten years, the computer has come of age in our world of technology. Computer aided advances in space technology or in the field of medicine are perhaps more spectacular, but

Oregon State University.

the computer has also become an efficient tool in agricultural research. The cereal breeding program at Oregon State University has benefited significantly from the use of the computer in clerical and research applications as well as for in-field data analysis.

In plant breeding programs where each year new F1 plant populations are created through hybridization, it can become a logistics problem to keep track of the hundreds of crosses that are made. This problem can become especially large when individual plants are selected in each succeeding generation and lines are bulked in later generations for yield tests. At any given point in time, the plant breeder has literally thousands of individual plants, rows, and plots, each unique and a potential varietal candidate.

To efficiently keep track of the experimental material, the computer has proven itself to be a valuable clerical assistant. A record is created for each new F1 and the computer updates the selection number through each cycle of selection. As a result, field book pages, tags for field identification of each line, and gummed labels which are used to identify the sacks of harvested seed can be printed. This clerical process used to take several people over a month to rewrite pedigrees each year. Now the computer can print the information overnight and transciption errors have been considerably reduced. Standardization of pedigrees and cultivar abbreviations has also facilitated the use of the computer to search for the frequency that particular parental sources have been used in hybrid combinations. Aided by such information, the plant breeder can more effectively plan and direct the breeding program to solve the more pressing problems limiting further genetic advance.

The selection number, which is updated each year by the computer and is unique for each line, can be a wealth of valuable information to the plant breeder. The number alone can tell the breeder the year the cross was made, the current generation, how the cross was made, the environmental and disease stresses the line has been subjected to throughout the selection cycle and at what generation it was first put under yield tests. The selection number can easily facilitate a computer search to determine the number of lines originating from a particular cross indicating to the breeder those crosses which appear to give the highest number of desirable progeny.

The computer can also be useful in cataloguing genetic differences found in the breeding material such as height, winterhardiness, disease resistance, quality characteristics and many other traits. By utilizing the computer as a memory bank, the breeder is able to handle more parental material and effectively utilize greater genetic diversity. With this type of information coupled with how many times a particular parent has been used and the number of progeny still remaining in the breeding program, he can plan more intelligently with less wasted effort on unproductive parental combinations.

It should be stressed that the computer will never take the place of the plant breeder in the field nor can it substitute for his knowledge and familiarity with the parental material. There are many nebulous characteristics that cannot be reduced to the elementary level necessary for computer cataloguing, so a good plant breeding program will always require the trained "artistic" eye of a plant breeder who is very familiar with the attributes of his parental lines. The computer's greatest contribution is realized when it is used as a memory bank from which pertinent information can be recalled for use by the plant breeder.

At Oregon State University, the computer is utilized to analyze the results of the International Winter x Spring Wheat Screening Nursery which is sent to over 100 locations throughout the winter wheat growing areas of the world. At each site cooperators collect data concerning height, lodging, winterhardiness, earliness, disease resistance, and grain yield. The information, over 250,000 readings, is loaded into the computer for analysis.

Because the goal of the nursery is one of screening material, the lines are not sent out in replications so standard analysis of variance statistical procedures cannot be used. A form of parametric statistics is employed. First the nursery at each location is analyzed individually. The information on each trait reported is ranked for all lines in the nursery from the most desirable reading to the least desirable. The highest ranked reading receives a score of 250, the next highest a score of 249, etc. Each line is thus assigned a score for each trait reported at a single location. These individual trait scores are then used to compute a weighted composite score for each line based on the following weighted percentages:

T1	Yield	.15		P1
T2	Earliness	.30		P2
T3	Winterhardiness	.24		P3
T4	Lodging	.01		P4
	Disease resistance	.30		P5
T5	*Puccinia striiformis*		.06	
T6	*Puccinia recondita*		.06	
T7	*Puccinia graminis tritici*		.06	
T8	*Septoria tritici or nodorum*		.06	
T9	*Erysiphe graminis*		.06	

The percentages are assigned to the traits based on the goals of the winter x spring wheat breeding program. Earliness, winterhardiness and disease resistance weigh more heavily than yield because of the nature of the nursery and the limited amount of seed provided.

So that the scores from all locations can be similarly compared independent of the number of traits reported by each cooperator, equalizer variable A is calculated:

$$A = P1 + P2 + P3 + P4 + P5$$

where P1, P2, ... P5 are the weighted percentages for each trait reported. If a particular trait is not reported P(n) becomes zero. The value of P5 is .30 even if only one disease is reported. Relative weighted percentages are calculated for each disease reported by the following formula:

$$B = .30 \ / \ \text{number of diseases reported}$$

A weighted composite score (WCS) for each line is then computed by the formula:

$$WSC = \frac{P1xT1 + P2xT2 + P3xT3 + P4xT4 + BxT5 + Bx\ T6 + BxT7 + BxT8 + BxT9}{A}$$

where P1, P2, ... P5 are the weighted percentages for each trait, T1, T2, ... T9 are the scores for each ranked reading, B is the relative weighted percentage for the diseases reported, and A is the equalizer variable calculated above.

Once the scores are computed for each line at each location they can be sorted and ranked giving tables of the superior lines at each location, the most promising lines for each individual trait, and the most promising lines for overall agronomic potential in low, intermediate and high rainfall zones.

The computer is able to sort, rank, and calculate scores utilizing hundreds of thousands of bits of information in less than one hour. Thus it is possible to print data summary booklets which are returned to each cooperator prior to the subsequent crossing season. This information is then available to aid the international cooperator in planning parental combinations the following year. Not only does he have data concerning the lines at his location, but he is also able to benefit from information returned on the material from all of the major winter wheat growing areas of the world.

Finally, the computer has become a valuable field assistant for the agronomist at harvest time. A small programmable calculator (Hewlett-Packard Model 9815) is interfaced to an electronic balance (Mettler PS15). A small gasoline-driven generator (Honda EM400) provides the electrical power so the complete system is portable and can be used directly in the field.

The calculator is programmed to prompt the user for certain necessary information making it possible to use the system without having any knowledge of computer programming or logic. As plots are harvested, the bags of grain are placed on the scale and the entry number and replication number are keyed into the calculator. In less than three seconds, the weight of the bag is transferred electronically to the calculator, printed on a paper tape and stored on a small magnetic tape cassette for later statistical analysis. Bags can be weighed in any order, but time is saved if nurseries are not mixed together.

Certain operating safeguards have been built into the calculator program. The user will not be allowed to enter an entry number or replication number which exceeds the limits of the nursery entered initially. If identifying numbers are entered for an entry for which a weight is already recorded, the calculator prints the weight that is recorded and asks the user if he wishes to record over the data. The electronic connection can be bypassed if desired and weights can be entered manually.

Upon completion of the weighing process, the calculator will search the tape and print identity numbers for any plots where yield data are missing. A printed list of all desired entries can be obtained. Then the calculator performs an analysis of variance for the yield nursery printing several useful statistical parameters such as the standard deviation, coefficient of variation, mean, and least significant difference. When prompted by the calculator, the user enters the minimum yield he feels is acceptable. The calculator searches the tape and prints the entry number and average yield of each entry in the nursery which exceeds this level. Finally, the calculator ranks the yield of all entries in a nursery listing the entry number, rank, and yield.

Since the statistical analysis is made immediately in the field after harvest, unpromising material can be discarded at the site and only the best retained for further testing. Once back at the main station, yield data are transferred electronically to a large computer and merged with other agronomic data such as maturity, disease reactions, height and data from previous years enabling the plant breeder to more effectively identify high yielding, stable, disease resistant cultivars which can be released to the producer.

Modern technology has made possible many innovative and useful applications of the computer, but the field is only in its infancy. Many exciting challenges lie ahead. We are limited only by our imagination.

Computer software mentioned in this paper is available upon request to the authors.

ACCELERATED WHEAT BREEDING PROCESS IN THE PHYTOTRON

Laszlo Balla
Hungary

The accelerated development of wheat production makes it essential for breeders to produce new varieties more quickly. The possibility of early selection has been exploited at many research centers but, even so, 14-15 years are required for the development and propagation of a new variety. If an attempt is made to solve a more complicated problem by multiple crossing, the breeding time becomes even longer and often 20 years are needed for the breeding and propagation of the variety. During such a long period wheat production changes so much that the new variety may be out of date even before it is produced. These facts are an incentive to shorten the wheat breeding process and increase its effectiveness.

At the same time the development of technology has made it possible to build phytotrons, or greenhouses with all modern conveniences in which winter wheat can be grown in an artifical environment independent of the external seasons. There is an ever-increasing number of such greenhouses and phytotrons. The first phytotron in Hungary was built at the Agricultural Research Institute of the Hungarian Academy of Sciences in Martonvasar (Rajki, 1973). This phytotron has been in operation since 1972 and one third of its capacity is devoted to wheat breeding.

If wheat breeding in an artificial environment is to be successful, several problems must be cleared up (Wellensiek, 1962). Mukade et al. (1975) studied how the germination of green seed and the vernalization period of intermediate wheats could be shortened. Moshkov and Hovanskaya (1978) reported a method for raising wheat more quickly.

The method for breeding winter wheat which has been elaborated at Martonvasar provides a theoretical basis for the production of a large number of combinations and, in practice, ensures the quickest possible plant propagation--the production of four generations a year (Balla, 1979a, b).

After the phytotron was built at Martonvasar the initial stage of wheat breeding was transferred from the field to the phytotron. But the phytotron still is only a latent possibility for the breeder. If it is to become a useful tool, he must learn to work in it and use it in the most efficient manner.

The phytotron presents the wheat breeder with the following possibilities:

1. a. The crossing and raising of several generations a year

Agricultural Research Institute of the Hungarian Academy of Sciences, Martonvasar

independent of the external seasons;

b. an increase in the number of hybrid combinations;

c. the production of complicated hybrid combinations in a shorter period of time;

2. frost resistance tests leading to selection, once a suitable method has been developed;

3. drought resistance tests; and

4. the theoretical and methodological experiments needed if successful work is to be carried out.

If several generations are to be grown, the following problems must be solved:

1. the state of dormancy in the germ must be terminated and normal germination achieved;

2. vernalization must be carried out under artificial conditions in the shortest possible time;

3. the development of planted seedlings must be regulated to achieve nicking at the flowering times of early and late varieties and to achieve the best possible seed-setting and highest possible yield;

4. determination of the earliest possible stage when harvesting can be carried out;

5. determination of the best method of crossing; and

6. development of a program for raising several generations.

If the work is carried out continuously, points 1 and 4 are interconnected.

In recent years numerous experiments have been done at Martonvasar to develop a wheat breeding technology adapted to the phytotron. The results of these examinations have made it possible to raise 2 X 2, i.e., a total of 4 generations a year and to produce plants equal in value to those raised in the field.

Wheat Breeding Technology in the Phytotron

1. Termination of the state of dormancy in the germ.

In theory, work in the phytotron is independent of the external seasons, but in practice it is adjusted to work in the fields. This is partly for organizational reasons and partly because new material is introduced into the phytotron after each field harvest.

If wheat is harvested under field conditions, the grain becomes dormant and does not germinate normally for around 30-40 days. Consequently, in order to start a new crossing program with new material it is ncessary to wait until the end of germ dormancy or to terminate dormancy artificially. Due to the co-ordination of work in the phytotron and in the field, germination is usually begun in the middle of August, before the end of dormancy. Cold treatment is a well-proved way of terminating dormancy. Germination is begun at 4° C for 48 hours and continued at 12° C. Thus, the wheat seeds are induced to germinate normally without the use of chemicals or bioregulators.

In the phytotron, wheat seeds are harvested before maturity, so they do not become dormant. Thus, they germinate normally.

2. Vernalization under artificial conditions.

Germinate wheat seeds are sown in soil and vernalized in the seedling stage. To be suitable for sowing the germ must be 5-10 mm long and of a size characteristic of the population. Such germs are sown individually in soil-filled plastic tubes 50-60 mm long and 20-25 mm in diameter. After germination for one day at room temperature during which time the seedlings emerge from the soil, they are transferred to the vernalization room where they are exposed to a temperature of 2° C and weak blue illumination.

When deciding on the length of the vernalization period it is impossible to consider the requirements of each variety and hybrid separately, partly because they are often unknown and partly because it would be technically very complicated. Consequently, a 45-day vernalization period is employed in all cases. This is sufficient even for varieties with the longest vernalization requirements. Tests have shown that for the varieties commerically grown in Hungary the longest vernalization requirement in the seedling stage is 40-45 days (Table 1).

Table 1. Vernalization requirements of registered wheat varieties, Martonvasar, 1977.

Variety	Days	Variety	Days
Mironovskaya 808	55	GK Tiszataj	40
Martonvasari 4	45	Bezostaya 1	40
GK-3	45	Martonvasari 7	40
Kompolti 1	45	Partizanka	40
Martonvasari 6	45	Sava	35
Martonvasari 5	45	Rana 1	35
Jubileinaya 50	45	Sadovo 1	35
Martonvasari 1	45	Rana 2	30
GKF-2	40		

In early varieties, however, or in those with a shorter vernalization requirement, the 45-day vernalization results in early heading. Thus, the difference between early and late varieties, as regards heading and flowering, will be greater and must be corrected later by means of development regulation.

Investigations are now in progress to obtain a reduction in the vernalization requirement. If the conditions are chosen correctly, it should prove possible to shorten the vernalization phase.

3. Regulation of the development and productivity of plants.

It is necessary to regulate plant development in order to: a) lengthen the flowering period; b) achieve nicking in the flowering of early and late varieties; and c) obtain a maximum number of ears and a good grain yield.

In the first phase of the research S. and E. Rajki worked out a basic program for raising the wheats grown in Hungary (Table 2). It was during this work that the need for development regulation arose.

Table 2. Program model for raising winter wheat in the phytotron.

Type and duration of program days	Temperature ° C		Illumination	
	night	day	Duration (hours)	Type of lamp
Spring 14				
1st-2nd week	15	16	13-1/4	Gro-Lux/WS + Cool-White
3rd-4th week	15	17	14	" "
5th-6th week	15	18	15	" "
Summer 7				
7th week	15	19	15-1/2	Gro-Lux/WS+Cool-White+ Incadescent
8th week	15	20	15-1/2	" "
9th week	16	21	15-3/4	" "
10th week	17	22	16	" "
11th week	17	23	15-3/4	" "
12th week	18	24	15-1/2	" "

Relative air humidity: until heading (up to 6th week) 65-75%
during flowering 80-85%

The flowering period must be regulated to be long enough to allow all the ears to be emasculated and pollinated. At Martonvasar, 1750 plants are raised in five GB units. The ratio of mother to pollinator plants is approximately 1:1. If one variety is used to pollinate a large number of mother plants, a smaller proportion (1: 0.8) of pollinators is sufficient. Calculating on emasculating and pollinating three ears per combination, three weeks are generally needed to carry out this number of crosses. Three ears are usually sufficient as this results in 60-120 hybrid grains.

Getting early and late varieties to flower at the same time is an important precondition for successful crossing. In the phytotron, where the conditions are more favorable for plant development than in the field, the flowering period is longer. The wheats grown in Hungary (early and mid-season varieties) flower for 7-10 days in the field and for 14-16 days in the phytotron. But this still does not allow early and late varieties to be crossed. The difference is even greater if extra-late varieties of northern origin are to be crossed with extra-early varieties from the south.

Development of wheat varieties is regulated by altering the temperature or the daylength, or by simultaneously changing both. The effect of these factors has been studied in several series of methodological experiments and a quantitative method of regulating wheat development has been elaborated based on the results.

Wheat development can be accelerated or retarded. In practice, the development of early varieties is generally retarded and that of late varieties accelerated. The best effect is achieved if treatment is carried out during phases 4-8 of the Feekes scale.

Development can be retarded by shortening the illumination period, decreasing the temperature, or both, and can best be accelerated by lengthening the illumination period, raising the temperature, or both. Wheat development can also be regulated by using different light sources; but, in this case, light sources which slow the development also lead to a decrease in productivity, so this method is best avoided.

In practice, the question presents itself in the form: how long a treatment is required and in which developmental phase to achieve an acceleration or retardation of X days in the development of the wheat? Figure 1 shows the retardation observed when the treatment was continuous throughout the wheat development period.

The effect of the treatment is weaker if it is restricted to certain phases of development. When treatment is carred out in the early phases the effect weakens or disappears later. The treatment is very successful if it is continued throughout at least four (5-8) phases of development as is shown in Figure 2.

Fig. 1.

Effect of temperature and daylength on the development of Bezostaya 1

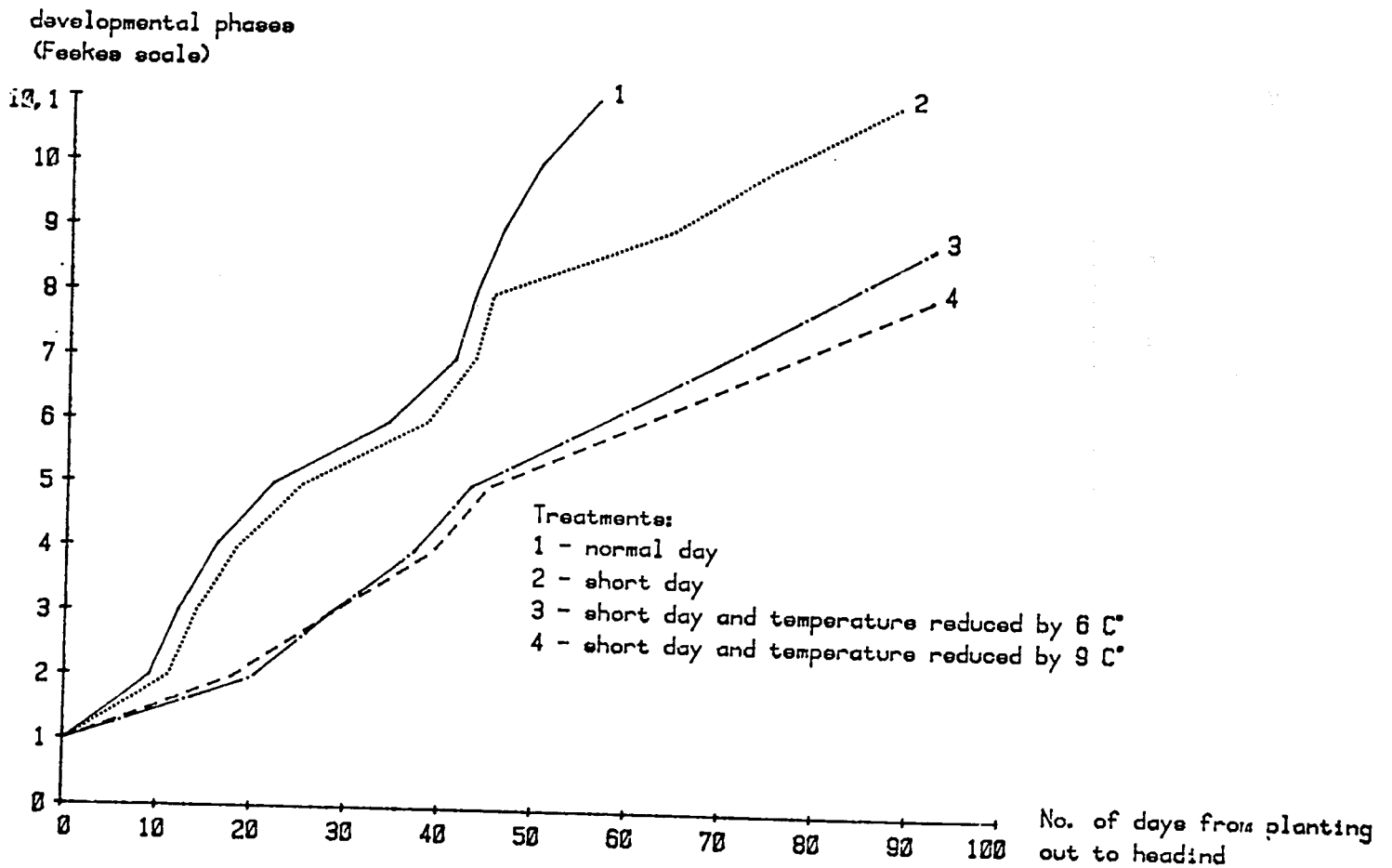
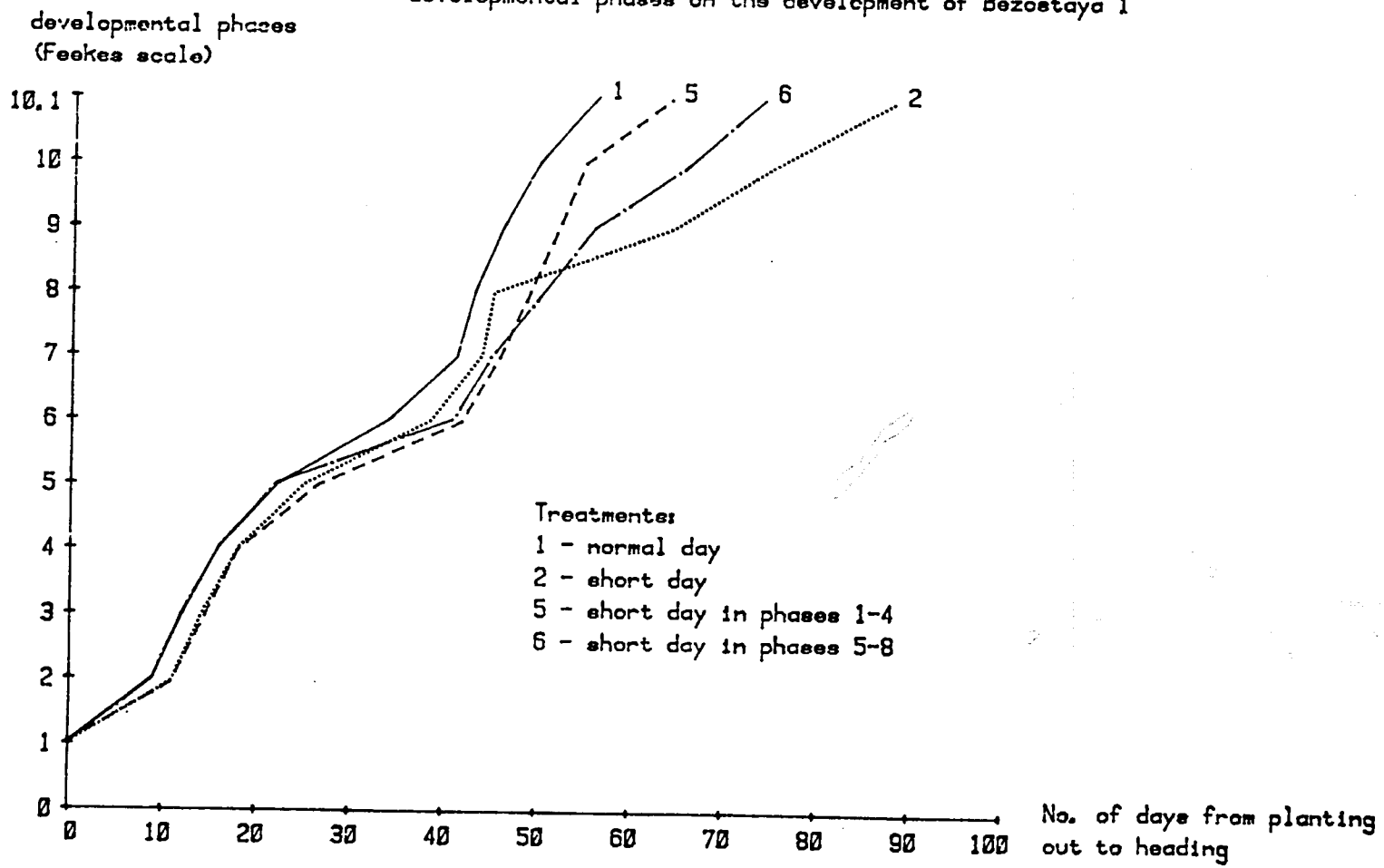


Fig. 2.

Effect of temperature treatment and daylength in various developmental phases on the development of Bezostaya 1



The effect of the treatment also depends on the type of variety Early varieties of southern origin, which are not sensitive to short days, react less to light treatment than late, long-day varieties of northern origin. Figure 3 shows that a short-day (10 hours) treatment carried out in developmental phases 5-8 retarded the growth of Sadovo 1 by 7 days and that of Bezostaya 1 by 15 days, while in Maris Huntsman the retardation was so great (23 days) that the wheat had still not headed at the end of the 90-day experimental period.

A more efficient way of retarding development is to combine shorter illumination with lower temperature. As can be seen in Figures 4 and 5, temperature is most effective if it deviates from the normal program by 6 or 9° C. Reducing the temperature by 3° C has very little effect.

In practice it is best to reduce the temperature by 9° C in the 9th phase of development. By this time, early heading varieties are easy to recognize and if these are subjected to a temperature reduced by 9° C with a normal illumination program, their development is retarded by almost as many days as the treatment lasts. For example, if plants are kept in the cold for 5 days, a retardation of 3-4 days is achieved, while with an 8-day treatment, the retardation is 6-7 days. At the same time, this temperature causes no reduction in the viability of the style or the pollen. If the treatment lasts for more than 7-8 days, the cold begins to have a deleterious effect with an increase in the number of sterile spikelets and a decrease in the grain number. Treatment in the 10th phase of development is less effective.

Crosses between varieties with different vegetation periods can be carried out more easily if the early variety is chosen as the mother plant. Emasculated ears can be kept on a normal program for 12-15 days, during which time the late, pollinating variety will head. Cold treatment is only justified if the difference is greater. If emasculated plants are exposed to cold, the style remains viable longer than on a normal program. Pollination can be carried out 2-3 days after the normal program is resumed.

The intensity of the various treatments must be such that no damage is caused to the development of the wheat and the greatest possible number of grains, i.e., the greatest productivity, is achieved. This must be taken into consideration because the aim of crossing is to obtain as many hybrid seeds as possible on one plant. The development-retarding treatments used at Martonvasar have had no significant effect on the number of shoots and productive ears, the plant height, the length of ear, the thousand-grain weight, or the number of grains per spikelet. However, treatments longer or more intensive than those described above caused an increase in the number of sterile spikelets and a reduction in the number of grains per ear, particularly if they were carried out in the 10th phase of development. Provided the treatment was not overdone, the yield components listed above were similar to those of the variant raised on a normal program (Table 3).

Fig. 3.

Effect of short day on the development of different wheat varieties

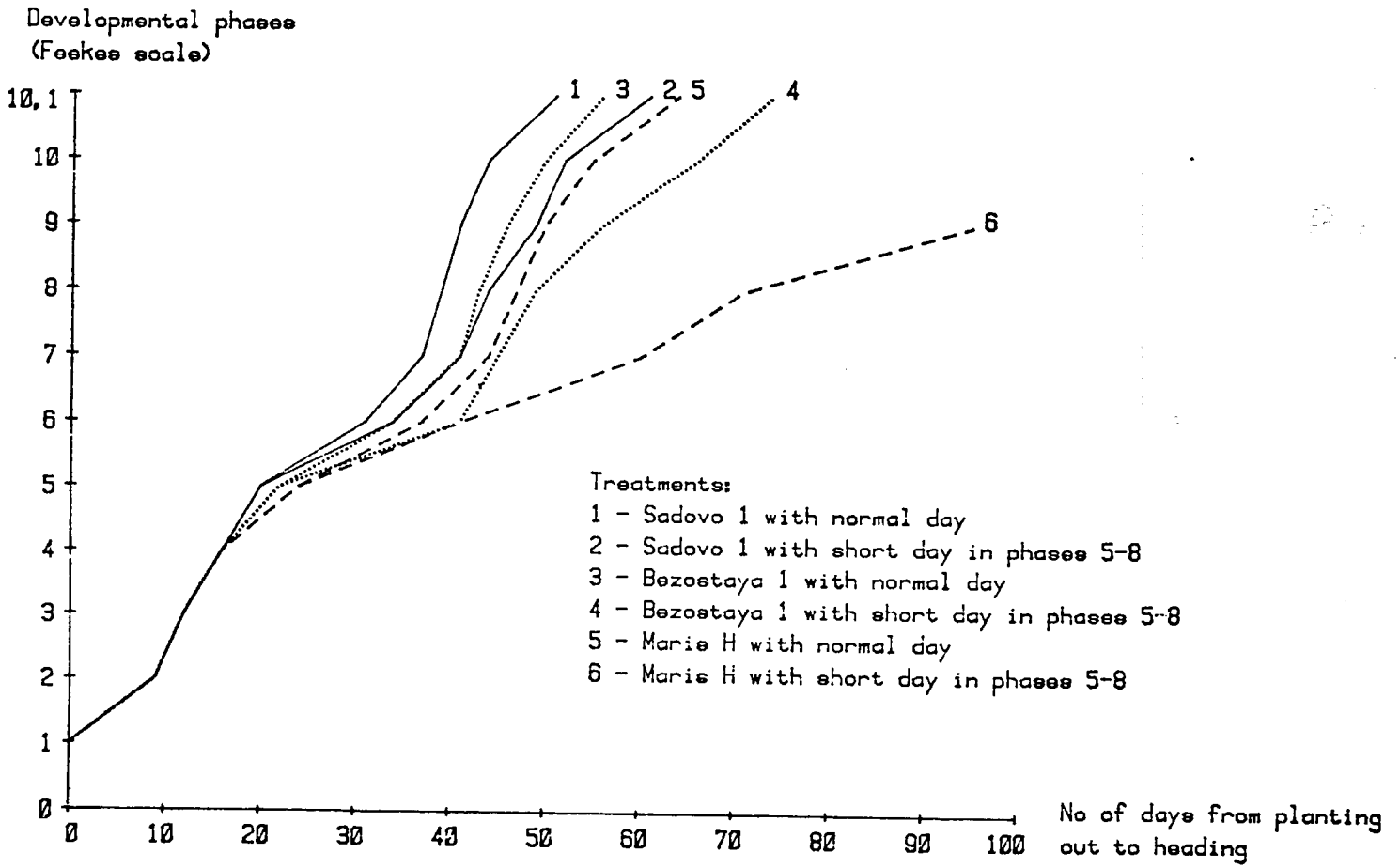


Fig. 4.

Effect of temperature treatment and daylength in various developmental phases on the development of Bezostaya 1

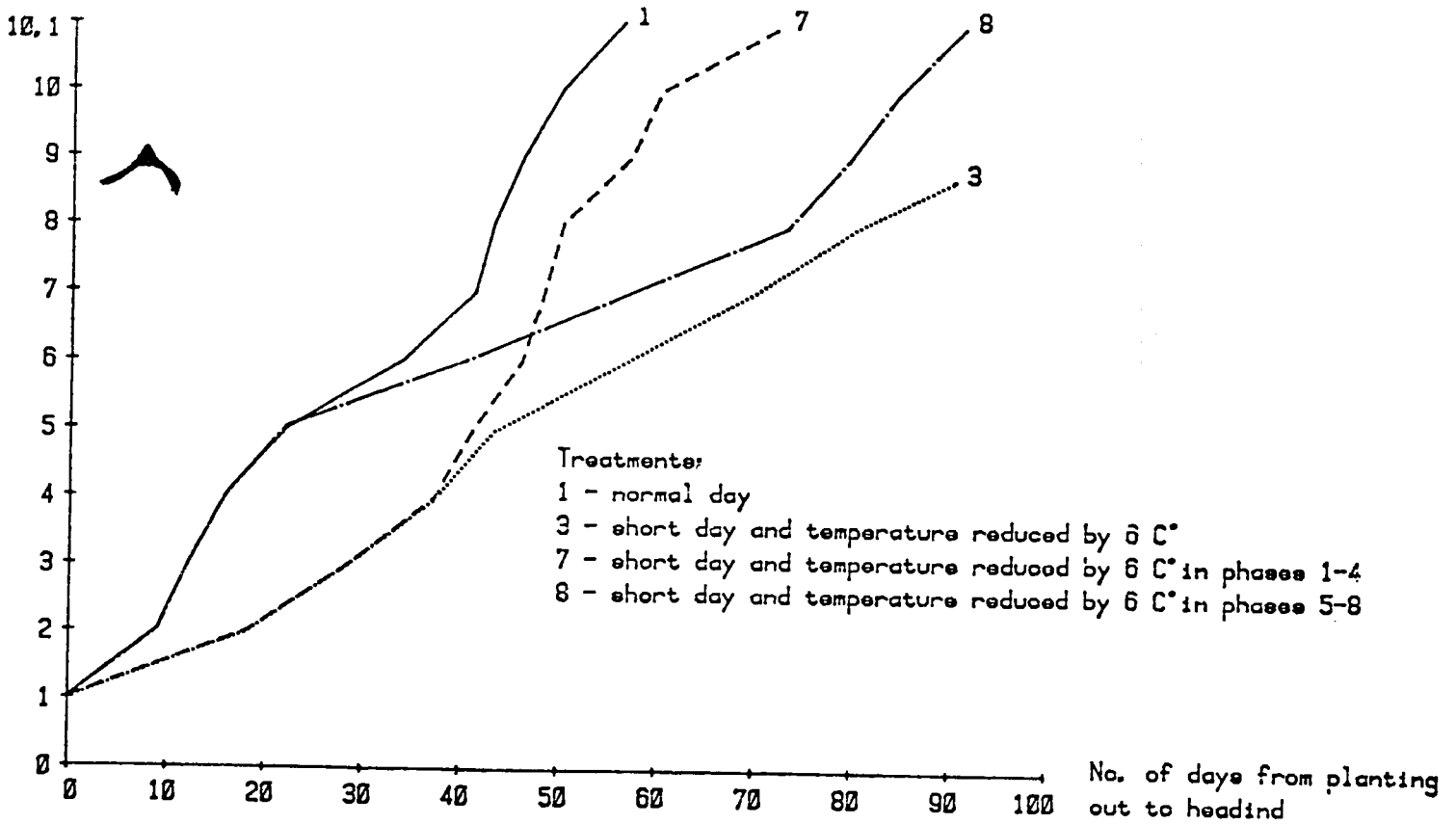


Fig. 5.

Effect of temperature treatment and daylength in various developmental phases on the development of Bezostaya 1

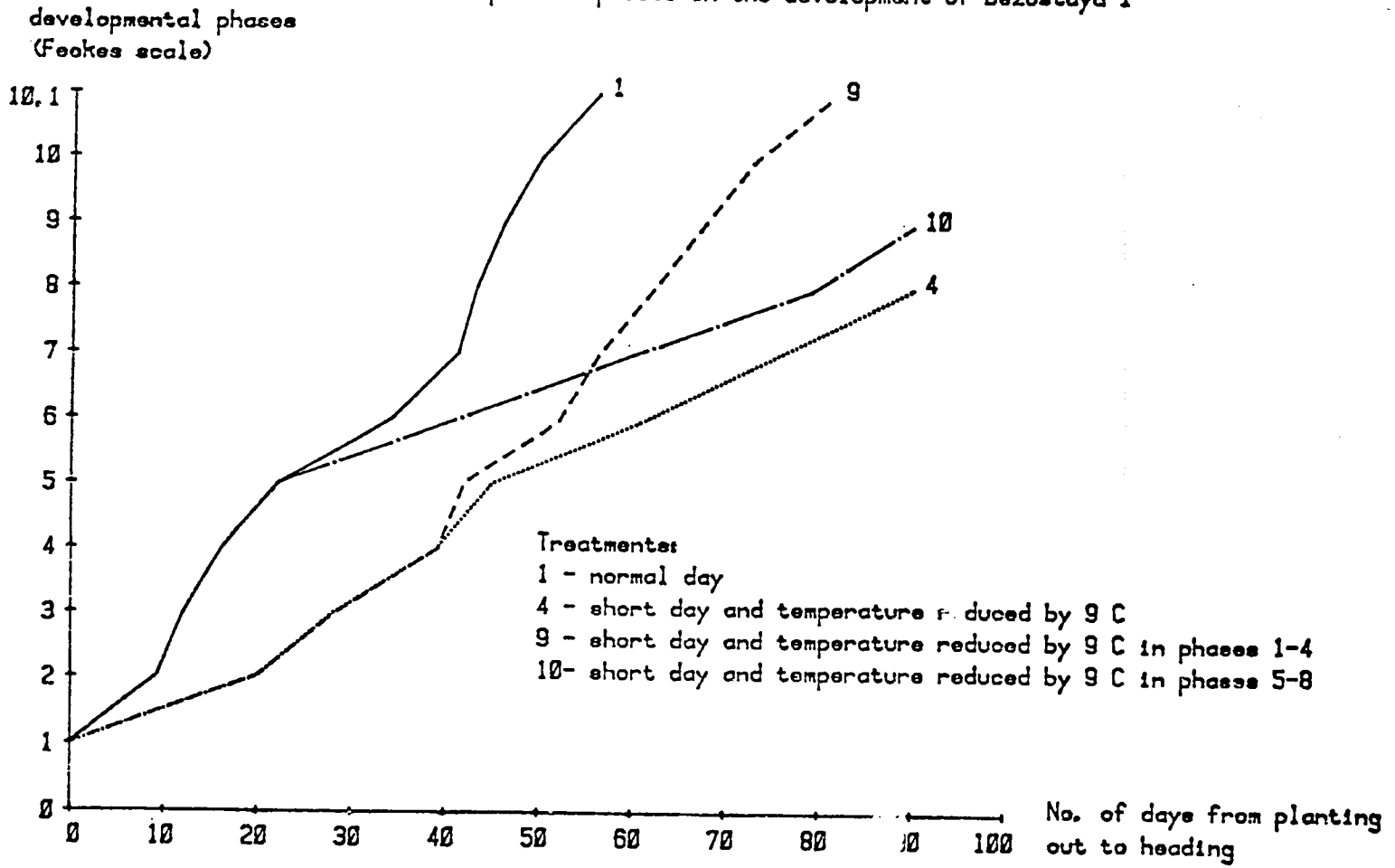


Table 3. Effect of short day illumination and low temperature on the yield components of Bezostaya 1.

Treatment	No. of sterile spikelets				No. of grains per ear			
	I	II	III	1/	I	II	III	1/
Control raised on normal program	0.6	0.6	0.6		39.9	39.9	39.9	
Control raised with short day (10 hours) illumination	6.2	1.5	4.8		35.4	48.4	32.5	
Treatment in development phase								
1-2	0.9	1.1	1.8		43.2	39.3	35.4	
3-4	1.1	2.0	1.8		37.0	36.4	39.0	
5-6	1.8	2.5	1.8		36.9	35.1	33.8	
7-8	2.1	2.1	1.9		35.8	35.1	39.8	
9-10	2.6	2.0	1.6		36.4	38.8	34.5	
1-4	1.4	2.7	1.1		37.6	37.6	38.9	
5-8	2.6	5.1	4.6		42.8	31.7	30.7	
9-10.5	2.1	6.0	10.0		36.3	31.3	14.6	

1/ I - normal temperature of program
II - temperature reduced by 6° C
III - temperature reduced by 9° C.

4. Determination of the earliest phase when harvesting can be carried out.

Under natural conditions 44-46 days are required from flowering to maturity. Under artificial conditions it is unnecessary to wait so long, since immature seeds are capable of germinating earlier. However, investigations had to be conducted to determine how many days were required after pollination to give a germination percentage acceptable to breeders, and what germination conditions should be provided. The first part of the study dealt with the germination conditions for embryos of various ages.

Wheat ears were harvested every two days from 2-22 days after fertilization and the germination of immature seeds was studies at 20, 12 and 4+20° C. The harvested seeds were germinated either immediately in the green stage, or after 3 days of drying in the ear or on filter paper, or after 12 weeks of drying in the ear. The seedlings were then planted out. It was found that with germination immediately after harvesting, 14 day old immature seeds were capable of germinating, whereas after 3 days of drying, 10 day

old seeds also germinated. After storing or drying for 12 weeks in the ear, even 2 day old immature seeds germinated. From the point of view of plant breeding, the best germination was obtained on at least 16 day old seeds which were dried after harvesting and germinated at 12° C (Table 4). After 12 weeks of drying 6-8 day old seeds also germinated well. The seedlings produced from these seeds remained alive after planting out and developed into plants suitable for propagation.

Table 4. Germination of Rannyaya 47 embryos of various ages.

Treatment	Age of embryo (days)						
	10	12	14	16	18	20	22
	at 20° C						
In the green state	0.0	0.0	6.7	23.0	20.0	6.7	0.0
Dried in the ear	3.3	6.7	13.3	30.0	33.3	60.0	33.3
Dried on filter paper	0.0	23.3	23.3	33.3	50.0	30.1	73.3
Control	88.4	88.4	91.7	91.7	90.0	88.4	85.0
	at 4 + 20° C						
In the green state	0.0	0.0	0.0	23.3	10.0	26.7	6.7
Dried in the ear	3.3	16.7	10.0	83.3	60.0	70.0	76.7
Dried on filter paper	3.3	16.7	43.3	46.7	93.3	96.7	73.3
Control	86.7	91.7	90.0	91.7	95.0	96.7	90.0
	at 12° C						
In the green state	0.0	0.0	16.7	6.7	33.3	66.7	26.7
Dried in the ear	6.7	16.7	56.7	90.0	100.0	100.0	96.4
Dried on filter paper	36.7	40.0	50.0	90.0	86.7	100.0	100.0
Control	95.0	90.0	93.4	93.4	95.0	98.4	88.4

In the second part of the study the germination of immature seeds of three wheat varieties was examined at 12° C for 2-48 days after fertilization and after 1-12 weeks of drying. Immature seeds harvested 6 days after fertilization and dried for a week germinated, but practically acceptable germination was only obtained for 18 day old embryos. As the drying time was increased, germination gradually improved with the seeds germinating earlier and more vigorously. After two or three weeks of drying, even 2 day old embryos proved capable of germinating and after 6, 8, or 10 weeks of drying, 90% of the 4-6 day old embryos germinated. The germination percentage depended on the variety (Table 5).

Table 5. Germination percentage of wheat embryos from 2-12 days old.

Drying time	Variety	Age of embryo (days) 2	4	6	8	10	12
1 week	Bez. 1	0.0	0.0	28.9	41.1	57.8	24.4
	Mv 5	0.0	0.0	23.3	31.1	40.0	15.6
	R-47	0.0	0.0	11.1	8.9	20.0	14.4
2 weeks	Bez. 1	0.0	61.0	41.1	54.4	6.7	30.0
	Mv 5	0.0	71.1	24.4	36.7	20.0	47.8
	R-47	14.4	25.6	38.9	34.4	21.1	31.1
3 weeks	Bez. 1	0.0	43.3	13.3	6.7	21.1	33.3
	Mv 5	33.3	47.8	15.6	16.7	32.2	62.2
	R-47	26.7	13.3	11.1	20.0	37.8	34.4
4 weeks	Bez. 1	0.0	52.2	3.3	82.2	73.3	83.3
	Mv 5	44.4	18.9	15.6	64.4	87.8	63.3
	R-47	22.2	7.8	26.7	67.8	83.3	77.8
6 weeks	Bez. 1	0.0	43.3	92.2	87.8	97.8	100.0
	Mv 5	70.0	92.2	62.2	85.6	98.9	100.0
	R-47	22.2	84.4	27.8	44.4	97.8	85.6
8 weeks	Bez. 1	0.0	70.0	31.1	88.9	96.7	86.7
	Mv 5	63.3	87.8	94.4	85.5	93.3	94.4
	R-47	62.2	53.3	84.4	66.7	85.5	85.5
10 weeks	Bez. 1	0.0	38.9	58.9	87.8	91.1	93.3
	Mv 5	57.8	94.4	73.3	85.5	95.5	94.4
	R-47	23.3	72.2	68.9	70.0	82.2	88.9
12 weeks	Bez. 1	0.0	63.3	81.1	93.3	88.9	96.7
	Mv 5	47.8	97.7	86.7	87.8	93.3	98.9
	R-47	64.3	76.7	91.1	77.8	96.7	95.6
Control	Bez. 1			92.6			
	Mv 5			95.4			
	R-47			94.9			

The question from the breeder's point of view is what age embryos it is best to harvest and how long they should be dried in order to obtain the highest percentage germination. This can be done in two ways.

1. After a week's drying 18-20 day immature seeds give good germination of over 90% which means plants can be raised from

practically every seed. In this case, seeds capable of germination will be available 25-27 days after fertilization.

2. After 6 weeks' drying 4-6 day old embryos also are capable of 90% germination. In this case, however, 46-48 days are required after fertilization before seeds capable of good germination are available.

If the aim is to speed up the generations the first method is more advantageous, but as regards the fullest exploitation of the phytotron, the second method is preferable. Consideration also must be given to where the immature seeds are to be sown. Under field conditions seeds which are too small may perish, but if they are to be sown in the phytotron again and vernalized artificially the germination will take place in the laboratory where the conditions will ensure survival.

Work in the phytotron can be calculated as follows: The flowering period of winter wheat is generally three weeks. The first pollination takes place 6-7 days after the beginning of flowering, while the last pollinations are carried out at the end of the third week, i.e., 14-15 days after the first pollination. It is advisable to wait until the seeds from the last pollination are 16-18 days old, at which time the first will be 22-25 days old. In such cases, the green weight of a thousand immature seeds will reach 50-60 g in all cases and after a week of drying they will be capable of over 90% germination (in the laboratory). Using this method, good results have been achieved for a number of years in the Martonvasar phytotron.

5. Determination of the best method of crossing.

Since plant raising in the phytotron involves a considerable amount of expense, the aim is to obtain as many seeds as possible from the least number of plants. But this is partly determined by the method of crossing. The known methods of pollination were studied in order to develop the most successful crossing method. The seed-setting percentage was examined from: a) hand pollination, b) restricted open pollination, and c) ear twirling.

The lowest seed setting was obtained with the classical method of hand pollination. Restricted open pollination gave better results. In this case, the flowering ears, standing in water, are kept under the isolator as the emasculated ear until the end of flowering.

The best result was obtained by ear twirling, when the flowering ear is held above the emasculated ear and is twirled to release the pollen onto the style. This method has now been successfully used in the field. Seed setting may be as high as 80%.

6. Program for raising four generations a year in the phytotron.

At present 2 X 2 generations can be raised from seed to seed in the phytotron each year without developmental compromises and by continuously operating the same growth units. Thus, of these four programs two are the progeny of the previous generations; III is the progeny of I and IV the progeny of II.

The programs consist of the following periods:

Vernalization	45 days
From sowing to heading	45 days
Flowering period	20 days
From end of flowering to harvest	20 days
TOTAL --	130 days

The time of the various phases could in fact be reduced but this would lead to deleterious results. If the vernalization period is shortened, the time from sowing to heading increases. If the time from sowing to heading is reduced, the plants produce fewer, smaller ears. Nor is it advisable to shorten the flowering period as this results in sterility and deficient seed setting and also leaves less time for crossing. With the above program, the plants produce three well-developed ears, and the crossing of three ears yields a total of 60-80 hybrid seeds.

In each crossing program approximately 300 combinations are produced and this requires five GB-48 growth units.

In essence, the GB-48 unit consists of a growth bench in which the air temperature, the air humidity, and the duration and intensity of illumination can be regulated. The useful area of each unit is 3.4 m^2, providing room for 350 vernalized plants. The switching on and off of the illumination occurs automatically in three intensity increments. In wheat experiments the illumination has a maximum of 16 hours.

The program elaborated for the raising of four generations begins after the harvest is completed in the field. This means that work in the phytotron and work in the field are connected. The raising program for the various generations is as follows:

Generation I :	start of vernalization	August 25th
	sowing date	October 9th
	beginning of heading	November 23rd
	end of heading	December 13th
	harvest	January 2nd
Generation II :	start of vernalization	November 20th
	sowing date	January 4th
	beginning of heading	February 18th
	end of heading	March 8th
	harvest	March 28th

Generation III:	start of vernalization	February 20th
	sowing date	April 6th
	beginning of heading	May 19th
	end of heading	June 8th
	harvest	June 28th
Generation IV :	start of vernalization	May 20th
	sowing date	July 4th
	beginning of heading	August 18th
	end of heading	September 7th
	harvest	September 27th

The raising of four generations is illustrated schematically in Figure 6.

In recent years a whole series of generations has been successfully raised in the Martonvasar phytotron and the developmental phases have always occurred at the times foreseen in the program. It should be noted that the program is designed for the wheat varieties commonly grown in Hungary. For early wheat varieties of southern origin a shorter program may be necessary, and for late northern varieties a longer program; the heat and light requirements of the various developmental phases may also be different.

Other Breeding Activities in the Phytotron

Frost resistance testing.--Several methods of testing for frost resistance are known, but most of them only give an approximate evaluation of this character. At Martonvasar a basic method of frost resistant testing was developed by E. Rajki (1980). The method has gradually been perfected and it is now possible to determine the frost resistance of lines or varieties with a single freezing.

The method is essentially as follows: The germinated wheat is sown in 42 X 30 X 14 cm wooden boxes at an even depth of 4 cm and is raised for 6 weeks on a program reflecting autumn conditions. During this period the wheat reaches the three-leaf stage of development. This is followed by hardening which is carried out in two phases. During the first phase the temperature fluctuates between +3 and -3° C for a week with 21-hours illumination at an intensity of 15,000 lux. During the second phase of hardening the temperature is -4° C for four days. At the beginning of the second phase the wheat is put into the frost chamber where the boxes are arranged at random. Air movement is created by ventilators throughout the freezing period. The temperature is gradually decreased, first to -12° C and then to -15° C. After 24 hours freezing, the plants are gradually thawed at +0.5° C. After two days, the boxes are transferred to a GB unit at 14-16° C where the plants are cut back, leaving a 1 cm stump. In the GB unit the frosted plants perish within three weeks while the surviving plants recover.

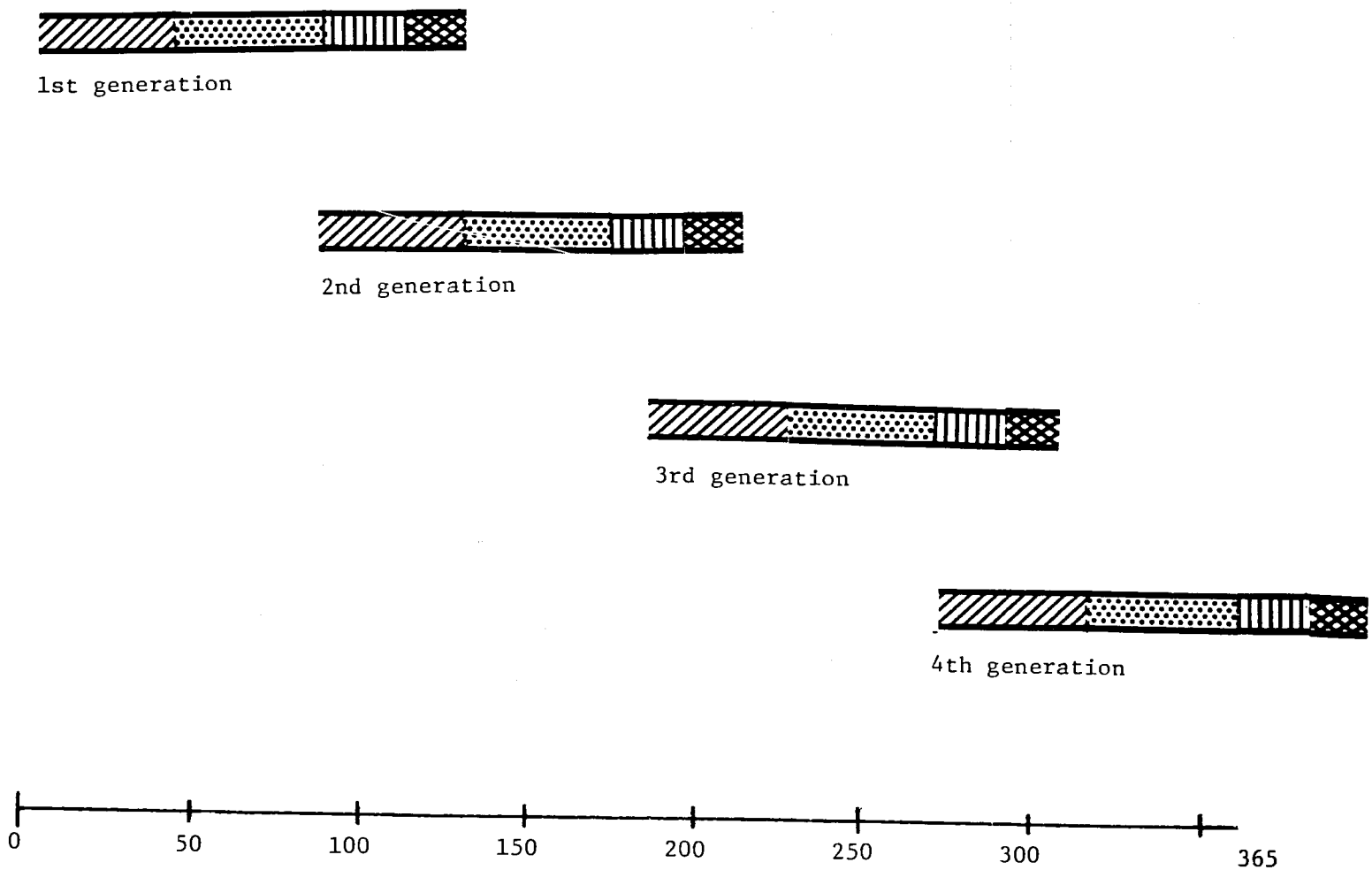


Figure 6. Sketch for the raising of four generations in the phytotron.

The frost test is carried out in four replications with 6 experimental and three standard varieties sown in each box. The tested stock is compared to the standards. The survival rate is determined on the basis of the plant number before and after freezing. The frost resistance of the wheat varieties registered in Hungary is illustrated in Table 6.

The data obtained in this way give a good picture of the frost resistance of varieties and lines. This is one of the most important factors in winterhardiness. In nature, however, the winter often produces other stresses (frostbite, frost lifting, etc.) and winterhardiness is also connected with the duration of the vernalization stage, winter dormancy, and development at low temperatures. Consequently, it may happen, particularly for less winterhardy varieties, that under natural conditions there is more frost damage than would be expected on the basis of the frost test. For frost resistant varieties there is less danger of this, though resistance to frost-lifting also depends on the strength of the root system.

Numerous other theoretical and methodological questions could also be clarified in the phytotron, leading to the more rapid achievement of breeding aims. So far, attention has been concentrated on solving the problems dealt with above but it is hoped that, in the future, solutions will also be found to other problems.

Summary

In order to utilize the phytotron in wheat breeding, a technique has been developed whereby 2 X 2, i.e., a total of 4 generations can be raised each year.

Cold treatment was found to be the most effective way of breaking dormancy. Germination takes place at 4° C for 48 hours, and then at 12° C.

Vernalization is carried out in the seedling stage at 2° C for 45 days in plastic tubes.

The effect of temperature, light and a combination of the two was investigated with a view to quantitatively regluating plant development. Nicking was achieved in the flowering of extra-early and extra-late varieties.

In examinations aimed at determining the earliest date at which harvesting can be carried out it was found that wheat can be harvested on the 18th day after pollination. By drying after harvest and germinating at 12° C a germination percentage of over 90% can be achieved. When working in the phytotron, harvesting can be carried out 18 days after the last cross which means that the first crosses are older and are even more certain to germinate.

Table 6. Frost resistance of registered wheat varieties in the phytotron, Martonvasar, 1977-1979.

Variety	Survival %			
	1977	1978	1979	Mean
Standards:				
Mironovskaya 808	72.8	93.1	87.3	84.4
Etoile de Choisy	49.4	20.3	37.4	35.7
Bezostaya 1	68.1	85.5	90.0	81.2
Varieties:				
Martonvasari 5	86.2	82.3	91.9	86.8
Jubileinaya 50	80.0	91.5	88.8	86.8
Martonvasari 1	83.5	90.9	83.2	85.9
Martonvasari 4	79.8	85.8	86.4	84.0
GK-3	82.3	83.2	--	82.8
Kompolti 1	81.6	77.3	83.5	80.8
Partizanka	68.8	82.5	85.4	78.9
GK Fertodi 2	70.5	74.8	--	72.7
Martonvasari 6	63.8	--	80.6	72.2
Martonvasari 8	72.8	58.8	82.7	71.4
GK Tiszataj	55.8	--	57.0	56.4
Martonvasari 7	51.3	--	54.2	52.8
Rivoli	21.2	41.7	--	31.5
Sava	35.1	4.2	27.8	22.4
NS Rana 1	13.8	30.8	17.9	20.8
NS Rana 2	10.0	16.0	16.6	14.2
Libellula	8.9	16.1	16.1	13.7
GK Szeged	15.0	0.0	19.1	11.4
NS Rana 3	6.3	4.2	10.3	6.9

Of all the known crossing methods ear twirling proved the most satisfactory.

A detailed description is given of the method devised for raising four generations a year. The method has been used in a number of programs and the individual development phases have always occurred at the predetermined times.

The method developed for testing frost resistance is also described. This is useful for predicting winterhardiness.

References

Balla, L. 1979a. Wheat breeding strategy in the Martonvasar phytrotron. Proc. of the Conference on Cytogenetics and Crop Improvement. Banaras Hindu University, Varanasi, India. March 3-8, 1978. (in press).

Balla, L. 1979b. Buzanemesitesi strategia a martonvasari fitotronban (Wheat breeding strategy in the Martonvasar phytotron). In A. Balint, A buza jelene es jovoje (The present and future of wheat). Mezogazdasagi Kiado, Budapest 1979. p. 43-50.

Moshkov, B. S. and N. V. Hovanskaya. 1978. Poluchenie v inskustvennih usloviah trjoh pokolenij ozimoj psenici v god. Dokladi VAHSNIL No. 1:4-6.

Mukade, K., M. Kamio, and K. Hosoda. 1975. Development of new procedures for accelerating generation advancement in breeding rust resistant wheat. Bulletin of the Tohoku Nation. Agr. Exp. Stn. No. 5. p. 1-45.

Rajki, E. 1980. Winterhardiness-frost resistance. Acta Agron. Hung., 29:451-468.

Rajki, S. 1973. Phytotron at Martonvasar for elucidating relationship between metabolism and heredity. Acta Agron. Acad. Sci. Hung. 22:295-301.

Wellensiek, S. J. 1962. Shortening the breeding-cycle. Euphytica 11:5-10.

GENETIC STUDIES OF SOME YIELD AND QUALITY COMPONENTS IN SPRING WHEAT

A. A. Abdel Bary, M. I. Ali and A. I. Nawar
Egypt

Abstract

In our search for high yield-high protein wheat strains, three introduced strains (Florence, Siete Cerros, and A35-213) together with the dominant Egyptian wheat cultivar (Giza 155) were used to study the genetics of yield and quality components. The studied traits were: 1) heading date, 2) plant height, 3) spike length, 4) number of spikelets per spike, 5) kernel weight, and 6) grain protein content. In addition, the interrelationships between these traits were estimated. Two crosses were made in 1974, 'Giza 155 X Florence' and 'Seite Cerros X A35-213', and their F_1s were grown in 1975. The F_2, P_1, P_2, BC_1, and BC_2 of each cross in addition to F_1 of the first cross were studied in 1976. The F_3, P_1, and P_2 of each cross were studied in 1977 under high and low levels of nitrogen.

Results indicated significant differences between the parents of each cross in most traits. Significant differences also were found between both F_2 and F_3 generation means and their parents in most of the studied traits. Frequency distribution curves of F_2 populations showed that all studied traits were of quantitative nature. Also a considerable amount of genetic variability reflected a relatively high heritability value for most traits. These results led to a reasonable amount of expected genetic advance by selection in these traits.

Analysis of gene action showed that all traits were governed by non-additive gene action of the additive X dominance type. In addition to dominance X dominance type in heading date, additive X additive in kernel weight, additive type of gene action in plant height and dominance type in both plant height and spike length were found.

Highly significant interaction effects between F_3 lines X fertility level indicated the necessity of further testing under different environments. Level of fertility had a considerable influence on the amount of variation and heritability estimates of most traits--especially protein content. It also influenced the correlation values between traits.

Correlation studies indicated highly significant values

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Crop Science Department, College of Agriculture, Alexandria University

between all studied traits except protein content with heading date, plant height and number of spikelets per spike. These results indicate the feasibility of selection for high levels of the studied traits. Besides it may be possible to select high protein strains different in plant height, heading date and yield performance.

Introduction

The gap between wheat production and consumption in Egypt is getting wider every year. After the Second World War, Egypt started importing increasing amounts of wheat to cover her needs. The rapid growth of population and the almost stable production led to increasing wheat imports. Since the wheat area is limited, the prospective approach becomes the introduction of high yielding cultivars together with the improvement of agricultural practices. The introduction of high yielding cultivars must be based on genetic studies of yield and yield components. High yielding wheat cultivars changed Mexico from a wheat-importing country to a self sufficient one in 1956.

The present work was designed to study the genetic behavior of yield components in some wheat crosses, together with protein content as the major quality factor. It is hoped that these basic studies will lead the way to the production of high-yielding, good-quality wheats for Egypt.

Several workers have studied the genetic behavior of wheat yield, yield components and wheat quality. There is a general agreement that most yield components are genetically controlled. However, the degree of heritability varies according to the material used and environmental conditions. Protein content, which is the major factor in wheat quality, also proved to be a heritable genetic trait. Again, different estimates of heritability of protein content were reported for different materials and environments.

In this study, three introduced lines were selected together with the dominant Egyptian cultivar, Giza 155. The three introduced lines are Florence, Siete Cerros and A35-213. Florence is an Australian variety introduced to the United States and it has been used extensively in breeding programs. Siete Cerros is a Mexican variety with high yield potential and broad adaptation. A35-213 is a Norwegian line derived from a species cross. The line was described by Aastveit (1968) as a high yielder with good quality. Two crosses were made in 1974. These were: cross 1, Giza 155 X Florence; and cross 2, Siete Cerros X A35-213. The F_1 was grown in 1975. In 1976, all the generations of each cross were included in a randomized complete block design. In 1977, the two parents and 100-200 random F_3 lines were included in a randomized complete block design with four

replicates. Plots were hills 30 cm apart spaced in both directions. Two replicates were provided with a low nitrogen level (25 kg N/ faddan) while the other two were given a high nitrogen level (75 kg N/faddan). The study aimed mainly to provide information on the four following objectives:

1) Evaluation of variation, heritability and prediction of genetic advance from selection in the progeny of the two crosses.

2) Determination of the association between different characters in the progeny of these crosses.

3) Determination of the effect of different nitrogen levels on variation, heritability and association between different traits.

4) Determination of the type of gene action controlling some major wheat traits.

Normal cultivation and statistical and genetical analyses were followed.

Results and Discussion

Six major wheat traits were considered. These were: 1) heading date, 2) plant height, 3) spike length, 4) number of spikelets per spike, 5) kernel weight, and 6) grain protein content. Results for each of these traits are presented and discussed in the same order.

Means and variances for all traits except protein for the parents, F_1, F_2, and backcrosses of crosses 1 and 2 in 1976-77 appear in Tables 1 and 2. Freguency distributions for the five traits in each of the crosses are plotted in Figures 1 through 10. Variance estimates and heritability estimates for the traits are summarized in Tables 3 and 4. Tables 5 and 6 contain estimates of gene effects for the five traits in cross 2.

Means and "T" values for differences between populations within crosses 1 and 2 under high and low levels of fertility in 1977-78 are contained in Tables 7 and 8. Appropriate analyses of variance mean squares for all traits at each fertility level of cross 1 are shown in Tables 9 and 10, and of cross 2 in Tables 11 and 12. Combined analyses mean squares for the six traits in cross 1 are given in Table 13 and in cross 2 in Table 14. Broad sense heritability estimates are reported in Table 15, correlation coefficients among traits in Tables 16 and 17.

Heading date--Parental differences in heading date were insignificant in the first cross and significant in the second cross. Heading date behaved as a quantitative character. The broad sense degree of heritablity varied between 36.1 and 98.5%.

Table 1. Means and variances of parental, backcrosses, F_2 generations, and "t" values for the differences between parental means of cross I, 1976-1977.

Population	Heading date (days)	Plant height (cm)	Spike length (cm)	Spikelets per spike (no.)	100-kernel weight (gm)
P_1 (G 155) mean	95.63	98.89	11.53	19.41	4.05
Variance	33.51	187.04	2.585	3.757	0.348
P_2 (Florence) mean	96.35	87.72	9.58	19.35	3.68
Variance	54.68	141.886	2.413	4.32	0.144
"t" value	0.71	6.52**	9.28**	0.23	5.00**
BC_1 mean	97.5	93.55	10.04	19.36	3.64
Variance	52.3	258.04	1.869	5.426	0.186
BC_2 mean	96.73	89.03	10.75	18.6	4.23
Variance	63.33	157.699	2.166	5.784	0.270
F_2 mean	96.26	92.166	10.116	18.265	4.061
Variance	66.965	286.459	2.259	4.304	0.218

Table 2. Means and variances of parental, backcrosses, F_1 and F_2 generations, and "t" values for the differences between parental means of cross II, 1976-1977.

Population	Heading date (days)	Plant height (cm)	Spike length (cm)	Spikelets per spike (no.)	100-kernel weight (gm)
P_3 (Sieto Cerros) mean	98.73	73.02	10.37	19.39	3.56
Variance	42.53	136.48	1.485	3.92	0.062
P_4 (A 35-213) mean	117.56	102.89	11.41	21.7	4.08
Variance	20.64	190.83	3.274	5.547	0.238
"t" value	20.27**	19.12**	4.52**	7.04**	8.00**
F_1 mean	103.93	96.03	11.71	20.79	3.79
Variance	68.56	221.99	2.062	5.506	0.079
BC_1 mean	99.43	88.3	11.04	20.47	3.79
Variance	61.65	301.99	2.117	4.769	0.061
BC_2 mean	100.26	96.48	10.56	20.27	3.75
Variance	47.08	266.007	2.68	4.556	0.081
F_2 mean	98.74	86.76	10.66	20.24	3.84
Variance	81.232	263.323	3.653	7.093	0.130

Table 3. Estimates of phenotypic, genotypic variances, and genetic coefficient of variability for five characters studied in the F_2 generation of cross I and II, 1976-1978.

Character	Cross I Variance Phenotypic	Cross I Variance Genotypic	Cross I C.V.%*	Cross II Variance Phenotypic	Cross II Variance Genotypic	Cross II C.V.%*
Heading date	66.965	24.16	5.11	81.232	37.322	6.19
Plant height	286.459	123.549	12.06	263.323	80.223	9.98
Spike length	2.259	-0.238	4.82	3.653	1.38	11.02
Spikelets per spike	4.304	0.28	2.89	7.093	2.102	7.16
100-kernel weight	0.218	-0.006	1.91	0.120	-0.006	2.01

* Genetic coefficient of variability.

Table 4. Heritability estimates in broad and narrow senses and expected genetic advance for five characters in the F_2 generation of crosses I and II, 1976-1977.

Character	Cross I h^2b.s.+	Cross I h^2n.s.+	Cross I Gs*	Cross II h^2b.s.	Cross II h^2n.s.	Cross II Gs*
Heading date	36.1	27.3	4.602	45.9	66.1	12.27
Plant height	43.1	54.8	19.106	30.4	--	--
Spike length	-10.5	21.3	0.712	37.7	68.6	2.7
Spikelets per spike	6.4	6.04	0.258	29.6	68.5	3.75
100-kernel weight	-2.7	--	--	-5.00	81.6	0.582

* Expected genetic advance from selection.

+ Heritability in broad- and narrow-sense, respectively.

Table 5. Gene effects estimated using an individual scaling test on means of parents, F_1, F_2, and backcrosses in cross II, 1976-1977.

Genetic parameter	Heading date	Plant height	Spike length	Spikelets per spike	100-kernel weight
A	-3.8 ± 2.441	7.55 ± 4.563	0.00 ± 0.397	0.76 ± 0.612	0.23** ± 0.976
B	-20.97** ± 2.378	-12.96** ± 4.637	-2.00** ± 0.48	-1.95** ± 0.647	-0.37** ± 0.104
C	-29.19** ± 2.85	-15.93** ± 4.833	-2.56** ± 0.519	-1.71* ± 0.782	0.14 ± 0.115

* Significant at the 0.05 level.
** Significant at the 0.01 level.

Table 6. Estimates of gene effects using a six-parameter model on means of parents, F_1, F_2, and backcrosses in cross II, 1976-1977.

Character	Genetic parameter					
	m	a	d	aa	ad	dd
Heading date	98.74** ± 0.388	-0.83 ± 1.433	0.205 ± 2.433	4.42 ± 3.278	8.585** ± 1.517	20.35** ± 6.439
Plant height	89.76** ± 0.676	-8.18** ± 2.84	15.095* ± 6.615	10.52 ± 6.304	10.255** ± 3.006	-5.11 ± 12.374
Spike length	10.66** ± 0.079	0.48 ± 0.263	1.38* ± 0.647	0.56 ± 0.893	1.00** ± 0.287	1.44 ± 1.173
Spikelets per spike	20.24* ± 0.11	0.20 ± 0.362	0.765 ± 0.915	0.52 ± 0.856	2.355** ± 0.410	0.67 ± 1.660
100-kernel weight	3.84** ± 0.015	0.04 ± 0.048	-0.31 ± 0.124	-0.28* ± 0.113	0.30* ± 0.127	0.42 ± 0.288

* Significant at the 0.05 level.
** Significant at the 0.01 level.

Table 7. Means of the P_1, P_2, and F_3 populations of studied characters and "t" value for the difference between the parental means, under high and low levels of fertility, cross I, 1977-1978.

Character	P_1		"t"	P_2		"t"	F_3		"t"
	High N	Low N	value	High N	Low N	value	High N	Low N	value
Heading date (days)	95.06	98.68	10.67**	92.44	98.22	17.05**	91.6	97.01	15.95**
Plant height (cm)	109.25	124.75	11.86**	105.11	115.05	3.82**	110.1	123.93	10.58**
Spike length (cm)	9.61	9.48	1.0071	8.65	8.55	0.775	9.24	8.63	4.72**
Spikelets per spike (no.)	18.76	18.45	1.519	18.42	19.11	3.38**	18.67	18.77	0.49
100-kernel weight (g)	4.56	4.73	3.61**	4.9	4.71	4.04**	5.13		5.53**
Protein percent (%)	13.48	8.37	50.09**	13.13	8.43	46.07**	13.06	8.48	44.9**

* Significant at the 0.05 level.

** Significant at the 0.01 level.

Table 8. Means of P_3, P_4, and F_3 populations and "t" value for the difference between the parental means, under high and low levels of fertility, cross II, 1977-78.

Character	P_3		"t"	P_4		"t"	F_3		"t"
	High N	Low N	value	High N	Low N	value	High N	Low N	value
Heading date (days)	96.03	99.37	14.977**	95.47	98.75	14.7**	95.04	96.64	7.17**
Plant height (cm)	100.97	106.62	6.52**	118.37	120.56	2.52*	112.99	116.94	4.56**
Spike length (cm)	10.18	9.02	14.68**	9.01	8.28	9.24**	9.84	8.83	12.78**
Spikelets per spike (no.)	18.3	18.99	4.36**	19.08	19.3	1.39	18.97	19.03	0.379
100-kernel weight (g)	4.26	4.63	12.75**	4.55	4.53	0.68	4.51	4.54	1.03
Protein percent (%)	13.33	8.61	5.32**	13.62	8.38	5.89**	13.18	8.36	5.42**

* Significant at the 0.05 level.

** Significant at the 0.01 level.

Table 9. Mean squares for the analysis of variance of the characters studied in cross I under high level of fertility, 1977-78.

S.O.V.	d.f.	Heading date	Plant height	Spike length	Spikelets per spike	100-kernel weight	Protein percent
Reps	1	24.7*	680.5*	21.7**	101.2**	0.09	3.3*
Lines	104	13.69**	158.37*	1.27*	2.8*	0.296**	3.56**
P_1	7	38.49**	132.29	1.91*	1.59	0.13	3.96**
P_2	8	7.56*	141.48	1.19	2.13	0.18**	10.61**
F_3	87	247.86**	160.96*	1.16*	3.01**	0.27**	2.93**
P_1 vs. P_2	1	59.97**	143.4	7.6**	0.95	0.95**	1.05
$P_1 + P_2$ vs. F_3	1	130.9**	240.5	0.37	0.19	4.49**	1.72
Errors	104	3.69	103.29	0.84	1.9	0.07	0.61
C.V.%		2.08	9.27	9.9	7.3	5.21	5.9
				Pertinent part of A.N.O.V.			
F_3	87	247.86**	160.96*	1.16*	3.01**	0.27**	2.93**
Error	104	3.69	103.29	0.84	1.9	0.07	0.61

* Significant at the 0.05 level.
** Significant at the 0.01 level.

Table 10. Mean squares for the analysis of variance of the characters studied in cross I under low level of fertility, 1977-78.

S.O.V.	d.f.	Heading date	Plant height	Spike length	Spikelets per spike	100-kernel weight	Protein percent
Reps	1	49.5**	1568.7**	0.38	3.9	0.12	9.4**
Lines	104	24.31**	98.1**	1.21**	3.42**	0.17*	0.74**
P_1	7	7.13	35.43	2.03**	2.77	0.16	2.13**
P_2	8	33.51**	89.06*	1.62*	2.72	0.3*	1.43**
F_3	87	24.72**	90.05**	1.01**	3.57**	0.16	0.58**
P_1 vs. P_2	1	1.8	791.6**	7.29**	3.8	0.004	0.04
$P_1 + P_2$ vs. F_3	1	58.9**	459.5**	4.07*	0.0013	0.612*	0.16
Error	104	6.44	46.99	0.64	1.79	0.125	0.31
C.V.%		2.6	5.56	9.2	7.12	7.28	6.57
			Pertinent part of A.N.O.V.				
F_3	87	24.72**	90.05**	1.01**	3.57**	0.16	0.58**
Error	104	6.44	46.99	0.64	1.79	0.125	0.31

* Significant at the 0.05 level.
** Significant at the 0.01 level.

Table 11. Mean squares for the analysis of variance of the characters studied in cross II under high level of fertility, 1977-78.

S.O.V.	d.f.	Heading date	Plant height	Spike length	Spikelets per spike	100-kernel weight	Protein percent
Reps	1	2.185	7.5	3.576**	32.72**	0.0005	13.1**
Lines	205	50.736**	268.77**	1.771**	4.233**	1.072**	2.998**
P_3	15	68.697**	164.56**	1.075	3.167	0.6367**	0.282
P_4	15	66.697**	586.9**	0.5464	1.734	1.768**	1.001
F_3	173	48.198**	221.842**	1.813**	4.51**	1.052**	3.442**
P_3 vs. P_4	1	5.062	4846.64**	21.82**	9.796*	1.318**	0.66
$P_3 + P_4$ vs. F_3	1	26.722**	601.46**	3.304*	4.34	0.6607**	2.53**
Errors	205	3.272	70.787	0.6799	2.358	0.0687	0.523
C.V.%		1.9	7.47	6.52	8.11	5.83	4.9
				Pertinent part of A.N.O.V.			
F_3	173	48.198**	221.842*	1.813**	4.51**	1.052**	3.442**
Error	205	3.272	70.787	0.6799	2.358	0.0687	0.523

* Significant at the 0.05 level.
** Significant at the 0.01 level.

Table 12. Mean squares for the analysis of variance of the characters studied in cross II under low level of fertility, 1977-78.

S.O.V.	d.f.	Heading date	Plant height	Spike length	Spikelets per spike	100-kernel weight	Protein percent
Reps	1	321.592**	7280.8**	1.584	3.65	0.5227*	8.6**
Lines	205	35.692**	232.334**	1.133**	3.902**	0.8451**	0.461**
P_3	15	17.966**	458.166**	1.587**	2.533	0.5944**	0.428
P_4	15	18.866**	166.108**	0.4751	0.8826	1.0092**	0.227
F_3	173	37.227**	199.695**	1.102**	4.315**	0.8611**	0.488**
P_3 vs. P_4	1	6.25	3107.062**	8.962**	1.482	0.1581	0.49
$P_3 + P_4$ vs. F_3	1	317.494**	610.108**	1.692*	0.685	0.063	0.55
Error	205	5.421	59.81	0.4089	2.027	0.0803	0.268
C.V.%		2.4	6.64	9.37	7.47	6.22	1.36
				Pertinent part of A.N.O.V.			
F_3	173	37.227**	199.695**	1.102**	4.315**	0.8611**	0.488**
Error	205	5.421	59.81	0.4089	2.027	0.0803	0.268

* Significant at the 0.05 level.
** Significant at the 0.01 level.

Table 13. Mean squares of the combined analysis of variance of the characters studied in cross I under high and low levels of fertility, 1977-78.

S.O.V.	d.f.	Heading date	Plant height	Spike length	Spikelets per spike	100-kernel weight	Protein percent
High vs. low	1	2954.752**	19502.485**	28.935**	1.431	5.148**	2254.255**
Reps/Exp.	2	37.1**	1124.5**	11.04**	52.55**	0.105	6.35**
Lines	104	21.17**	171.073**	1.812**	4.777**	0.3422**	2.516**
P_1	7	15.7**	103.4	1.62*	1.72	0.123	3.86**
P_2	8	21.625**	144.44	2.356**	3.67*	0.356**	7.253**
F_3	87	19.59**	164.696**	1.639**	5.228**	0.318**	2.029**
Lines X Fertility	104	16.824**	85.389	0.6675	1.443	0.1279*	1.781**
P_1 X Fertility	7	29.9**	64.285	2.324**	2.637	0.1595	2.226**
P_2 X Fertility	8	19.45**	96.1	0.4498	1.172	0.1237	4.784**
F_3 X Fertility	87	15.625**	86.301	0.5319	1.355	0.1087	1.477**
P_1 vs. P_2 X Fertility	1	19.64	130.59	0.005	4.288	0.5351*	0.7487
$P_1 + P_2$ vs. F_3 X Fertility	1	183.1**	17.54	3.31*	0.1131	0.878**	1.4675
Error/Exp.	208	5.061	75.136	0.7351	1.845	0.0961	0.4615
r F_3		0.484**	0.35o**	0.245**	0.206*	0.263**	0.567**
				Pertinent part of combined A.N.O.V.			
F_3	87	19.59**	164.696**	1.639**	5.228**	0.318**	2.029**
F_3 X Fertility	87	15.625**	86.301	0.5319	1.355	0.1087	1.477**
Error	208	5.061	73.136	0.7341	1.845	0.0961	0.4615

* Significant at the 0.05 level, r value at 0.05 level (n = 104) = 0.195.
** Significant at the 0.01 level, r value at 0.01 level (n = 104) = 0.245.

Table 14. Mean squares of the combined analysis of variance of the characters studied in cross II under high and low levels of fertility, 1977-78.

S.O.V.	d.f.	Heading date	Plant height	Spike length	Spikelets per spike	100-kernel weight	Protein percent
High vs. low	1	712.082**	3200.699**	207.261**	2.93	0.6799**	4888.66**
Reps/Exp.	2	161.188**	3644.15**	2.58**	18.185**	0.2616*	10.85**
Lines	205	63.646**	320.702**	2.215**	5.883*	1.810**	1.89**
P_3	15	64.81**	511.91**	1.95**	4.26*	1.11**	0.3871
P_4	15	61.699**	447.096**	0.719	1.127	2.402**	0.6771
F_3	173	62.856**	244.48**	2.197**	6.445**	1.838**	2.142**
Lines X Fertility	205	22.782**	180.402**	0.6889*	2.253	0.106	1.571**
P_3 X Fertility	15	21.839**	110.824**	0.7128*	1.4402	0.121	0.3242
P_4 X Fertility	15	23.866**	305.912**	0.3030	1.4904	0.375**	0.5516
F_3 X Fertility	173	22.569**	177.057**	0.7193*	2.3805	0.075	1.788**
P_3 vs. P_4 X Fertility	1	0.031	94.257	1.406	1.828	1.1944	1.1436**
$P_3 + P_4$ vs. F_3 X Fertility	1	79.998**	0.012	0.133	0.788	0.1437	0.3670
Errors/Exp.	410	4.346	65.299	0.5444	2.192	0.074	0.3960
r F_3		0.266*	0.42**	0.254*	0.269**	0.039	0.689**
				Pertinent part of A.N.O.V.			
F_3	173	62.856**	244.48**	2.197**	6.445**	1.838**	2.142**
F_3 X Fertility	173	22.569**	177.057**	0.7193*	2.3805	0.075	1.788**
Error	410	4.346	65.299	0.5444	2.192	0.074	0.3960

* Significant at the 0.05 level, r value at 0.05 level (n = 204) = 0.138
** Significant at the 0.01 level, r value at 0.01 level (n = 204) = 0.181

Table 15. Heritability in broad sense for characters studied in crosses I and II under two levels of nitrogen, 1977-1978.

Character	Cross I		Cross II	
	High nit.	Low nit.	High nit.	Low nit.
Heading date	98.5	73.9	93.2	85.4
Plant height	35.8	47.8	68.0	70.0
Spike length	27.5	36.6	62.4	62.8
Spikelets per spike	36.8	49.8	47.7	53.0
100-kernel weight	74.0	21.8	93.4	90.6
Protein percentage	79.1	46.5	84.8	45.0

Table 16. Simple correlation coefficients between pairs of characters studied in the F_3 of cross I under high and low levels of fertility, 1977-78.

Character	Plant height		Spike length		Spikelets per spike		100-kernel weight		Protein percentage	
	High N	Low N	High N	Low N	High N	Low N	High N	Low N	High N	Low N
Heading date	0.85**	-0.095	0.029	-0.013	0.194	-0.04	-0.053	-0.024	-0.196	-0.158
Plant height			0.265*	0.326**	0.335**	0.179	-0.017	0.09	-0.182	0.033
Spike length					0.278**	0.035	-0.176	0.141	0.199	-0.027
Spikelets per spike							-0.047	-0.053	-0.053	-0.172
100-kernel wt.									-0.016	-0.003

* Significant r at 0.05 level (n = 88) = 0.205
** Significant r at 0.01 level (n = 88) = 0.267

Table 17. Simple correlation coefficients between pairs of characters studied in the F_3 of cross II under high and low levels of fertility, 1977-78.

Character	Plant height		Spike length		Spikelets per spike		100-kernel weight		Protein percentage	
	High N	Low N	High N	Low N	High N	Low N	High N	Low N	High N	Low N
Heading date	0.449**	-0.077	0.531**	-0.146*	0.513**	0.299**	-0.457**	-0.139**	0.088	-0.147
Plant height			0.380**	0.700**	0.274**	0.594**	-0.433**	0.639**	-0.326**	0.071
Spike length					0.429**	0.349**	-0.344**	-0.416**	-0.026	0.553**
Spikelets per spike							-0.443**	-0.417**	-0.015	0.084
100-kernel wt.									0.172	-0.269**

* Significant r at 0.05 level (n = 174) = 0.138
** Significant r at 0.01 level (n = 174) = 0.181

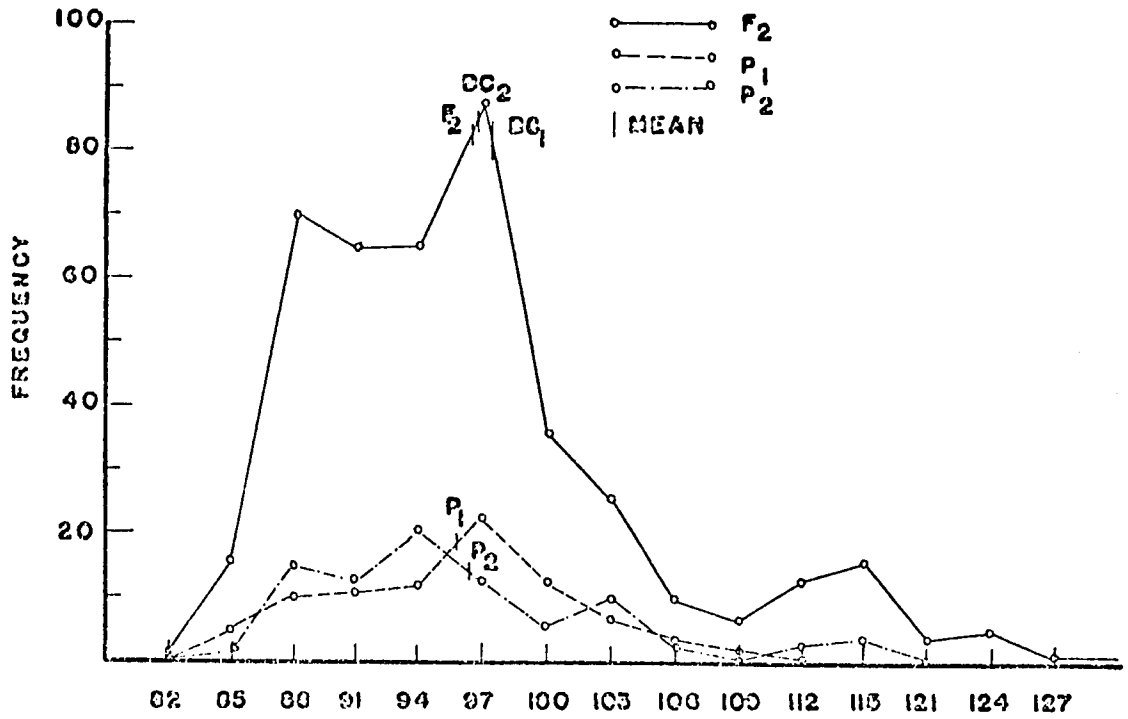


FIG. 1: FREQUENCY DISTRIBUTIONS FOR HEADING DATE IN P_1, P_2 AND F_2 POPULATIONS OF CROSS I, 1976-1977.

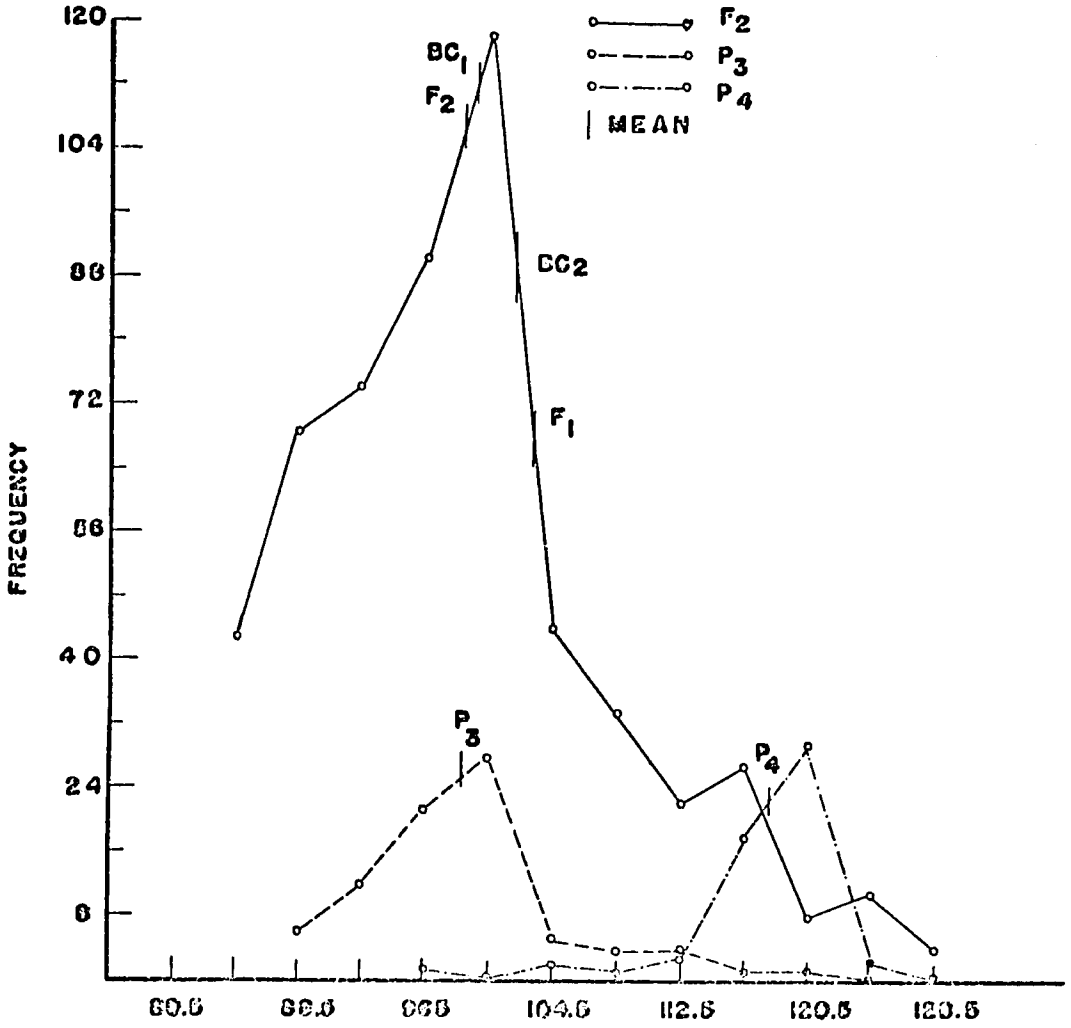


FIG.2: FREQUENCY DISTRIBUTIONS FOR HEADING DATE IN P_3, P_4 AND F_2 POPULATIONS OF CROSS II, 1976-1977.

The narrow sense heritability ranged between 27.3 and 66.1%. Heritability estimates were higher under high nitrogen level. Genetic variation in the F_2 generation was between 1.9 and 6.19%. Gain from selection varied between 4.6 and 12.3%. The F_3 lines varied significantly in heading date for both crosses under both nitrogen levels. Type of gene action involved in the inheritance of this trait was found to be mainly due to epistatic effects.

These results indicate that there is a potentiality for selecting lines with either early or late heading date in the derived lines from these two crosses. The mean number of days for heading was 95.6 for the local variety Giza 155, 96.4 for Florence, and 98.7 for Siete Cerros and 117.6 for the Norwegian strain A35-213. There is a difference in heading date of more than 3 weeks between the early and the late parents.

These results are in general accordance with other workers, Frey (1954a), Jogi (1956), Johnson and Frey (1967), Bhatt (1972), Tikka et al. (1973) and Ketata et al. (1976a).

Plant height--Means of plant height were 98.9 cm for Giza 155, 87.7 cm for Florence, 73.0 cm for Siete Cerros and 109.9 cm for A35-213. Parents of each cross differed significantly in plant height. The genetic coefficient of F_2 variability was 12.06% for cross 1 and 9.98% for cross 2. Distribution curves of both crosses indicated the quantitative genetic nature of plant height. Broad sense heritability varied from 43.0% for cross 1 to 30.4% for cross 2. The narrow sense heritability value was 54.8% for the first cross. The expected genetic advance from selection for plant height was high in the first cross, reaching 19.1%, but it was not estimated for the second cross due to the negative additive component of variance of the narrow sense heritability.

The results indicated that the type of gene action controlling plant height is mostly of the additive type. Besides, the F_3 lines in both crosses were significantly different in plant height under both nitrogen levels. However, the estimates of heritability were higher under low nitrogen levels.

Again these results indicated the potentiality for selecting the desirable plant height for Egyptian wheat crops ranging from 73 cm up to 117 cm. The straw yield varies in value from one country to another according to the availability of roughage for animal feed.

These results are again in general agreement with those from most workers (Frey and Horrer (1955), Johnson et al. (1966), Bhatt (1972), Edwards et al. (1976), and Ketata et al. (1976c)).

Spike length--Parental differences in spike length were significant in both crosses. The F_2 coefficient of genetic

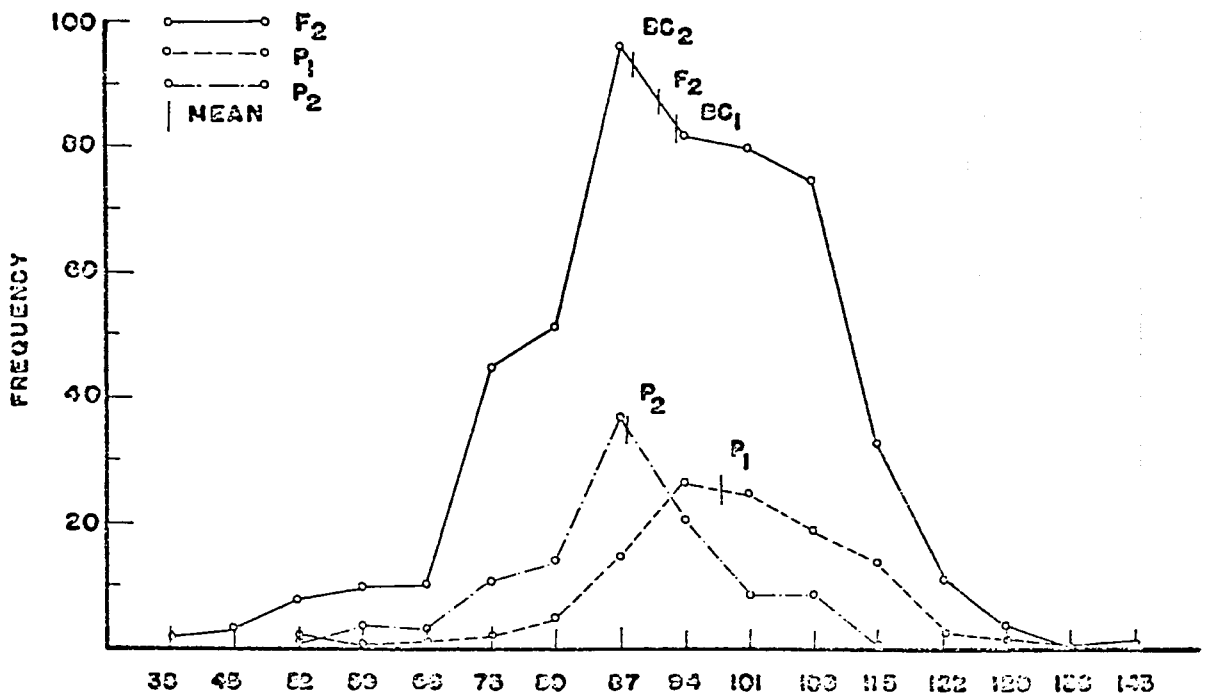


FIG. 3: FREQUENCY DISTRIBUTIONS FOR PLANT HEIGHT IN P_1, P_2 AND F_2 POPULATIONS OF CROSS I, 1976-1977.

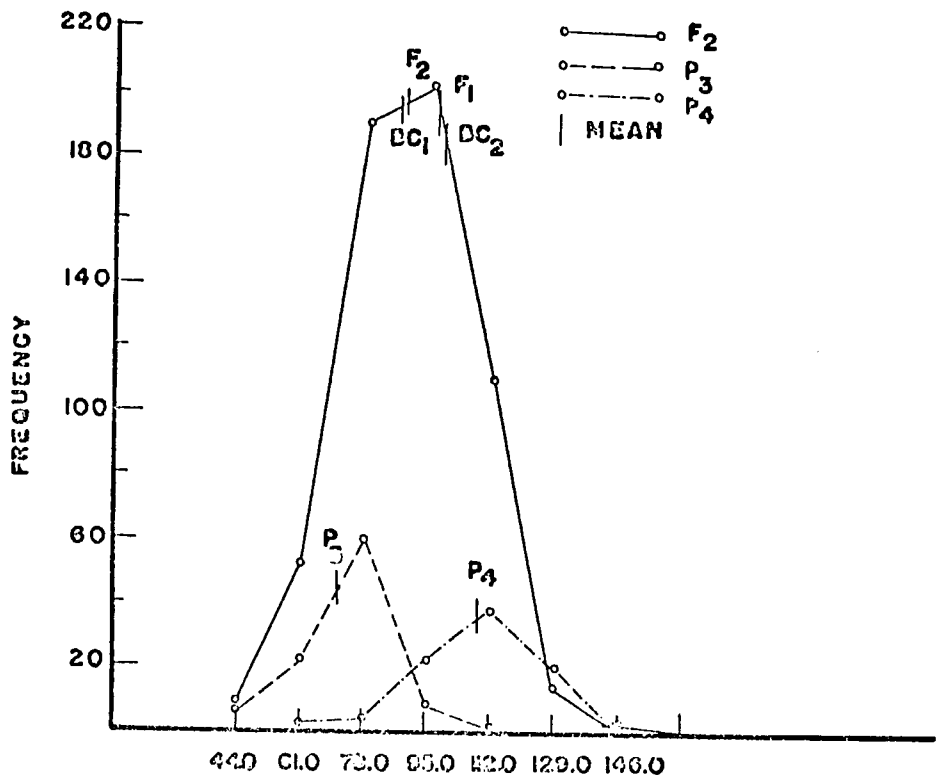


FIG. 4: FREQUENCY DISTRIBUTIONS FOR PLANT HEIGHT IN P_3, P_4, AND F_2 POPULATIONS OF CROSS II, 1976-1977.

variation ranged between 4.82 and 11.02%. Broad sense heritability estimates varied between 27.5 and 62.8%. Narrow sense heritability estimates varied between 21.3 and 68.6%. Expected genetic gain from selection for spike length varied from 0.7 to 2.7%. The prevailing type of gene action was the dominance and esistasis. Nitrogen level had no significant effect on heritability estimates of spike length.

The non-additive type of gene action could be responsible for the low response of genetic advance from selection for spike length.

These results are generally in accordance with results of several workers (Petr and Frey (1966), Johnson and Frey (1967), Walton (1972), Rana et al. (1973), and Albrecht (1976)).

Number of spikelets per spike--This was the fourth trait studied. Mean number of spikelets per spike was 19.41 for the local cultivar Giza 155. Florence and Siete Cerros had a similar number of 19.35 and 19.39, respectively. The Norwegian line had the highest number of spikelets of 21.7. Parental means in cross 1 did not reach the level of significance and F_2 genetic variability was only 2.9%. In cross 2, the parental means were significantly different. The F_2 distribution showed no segregation for definite groups. The F_2 genetic coefficient of variation was 7.2%.

Heritability estimates and genetic advance from selection were low for cross 1 and relatively high for cross 2. In cross 2 the broad and narrow sense heritability values were 29.6 and 68.5 percent, respectively, leading to a genetic advance of 3.75%.

High level of nitrogen led to lower heritability estimates. Epistasis of additive X additive genetic variance dominated the spikelets per spike. F_3 lines of both crosses were genetically different. In spite of the difficulty of isolating lines with a high number of spikelets per spike, it is a trait which should be given emphasis due to its direct contribution to yield.

These results agree in general with results of several workers (Johnson and Frey (1967), Fonseca and Patterson (1968), Walton (1972), and Ketata et al. (1976a)).

Kernel weight--Mean 100-kernel weight was 4.05 grams for Giza 155, 3.68 for Florence, 3.56 for Siete Cerros and 4.08 for the Norwegian line. Parental differences were significant in both crosses. The genetic coefficient of variation was 1.91% for cross 1 and 2.01% for cross 2. Heritability in broad sense was low and negative in both crosses. This perhaps was due to the high environmental variance of the parents and F_1. In cross 2, however, the narrow sense heritability value was 81.6%, leading to a relatively high expected genetic advance of 0.6%. Type of gene action governing the inheritance of kernel weight was found to be epistatic.

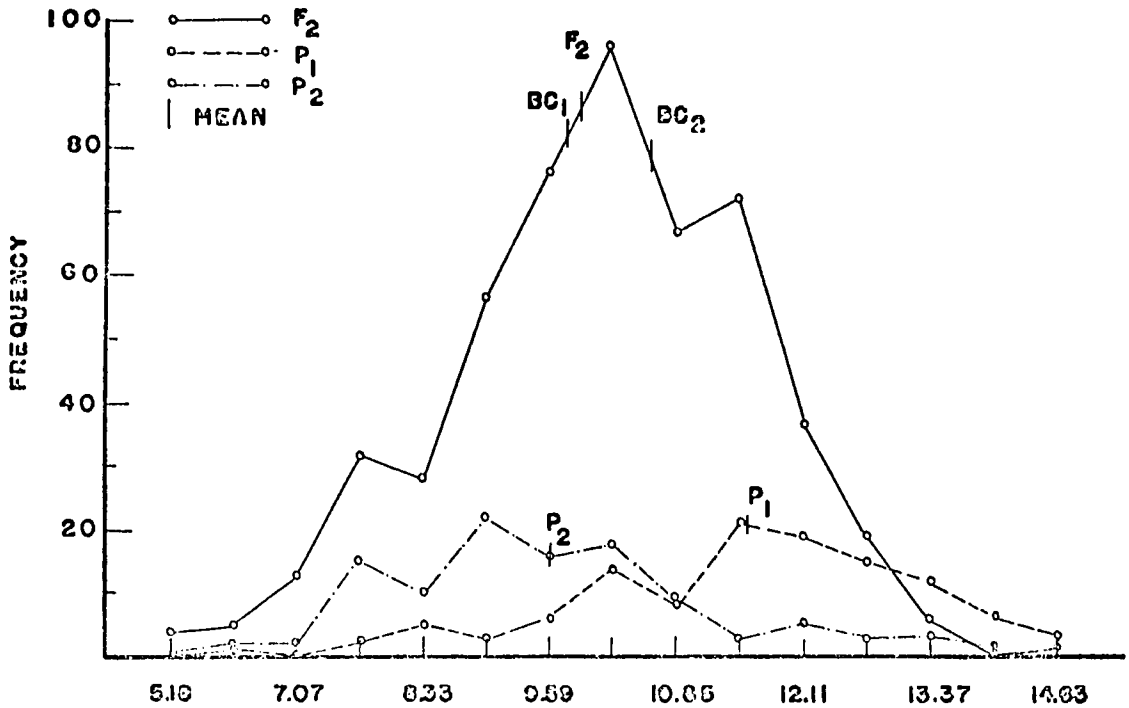


FIG.5: FREQUENCY DISTRIBUTIONS FOR SPIKE LENGTH IN P_1, P_2 AND F_2 POPULATIONS OF CROSS I, 1976 - 1977.

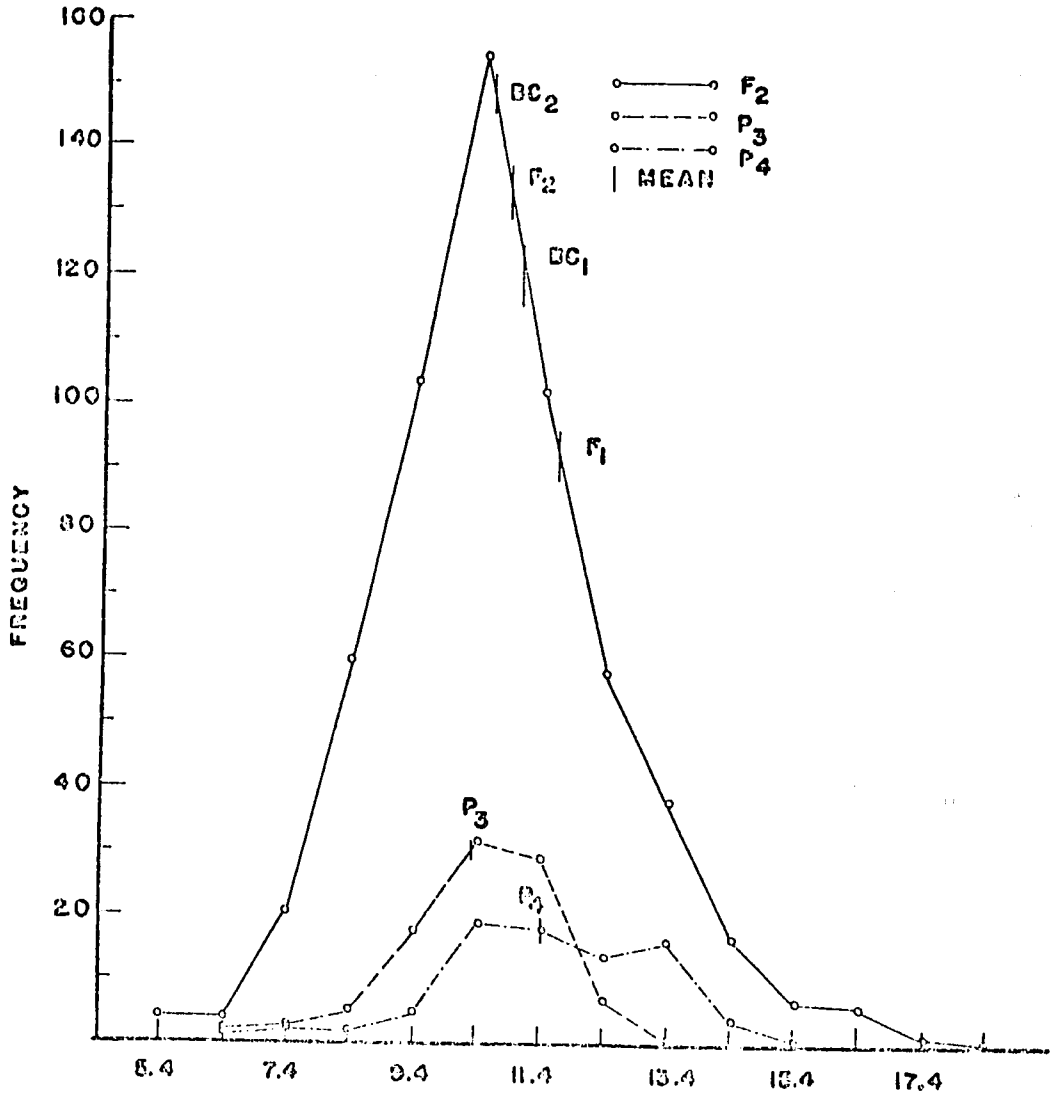


FIG.6: FREQUENCY DISTRIBUTIONS FOR SPIKE LENGTH IN P_3, P_4 AND F_2 POPULATIONS OF CROSS II, 1976-1977.

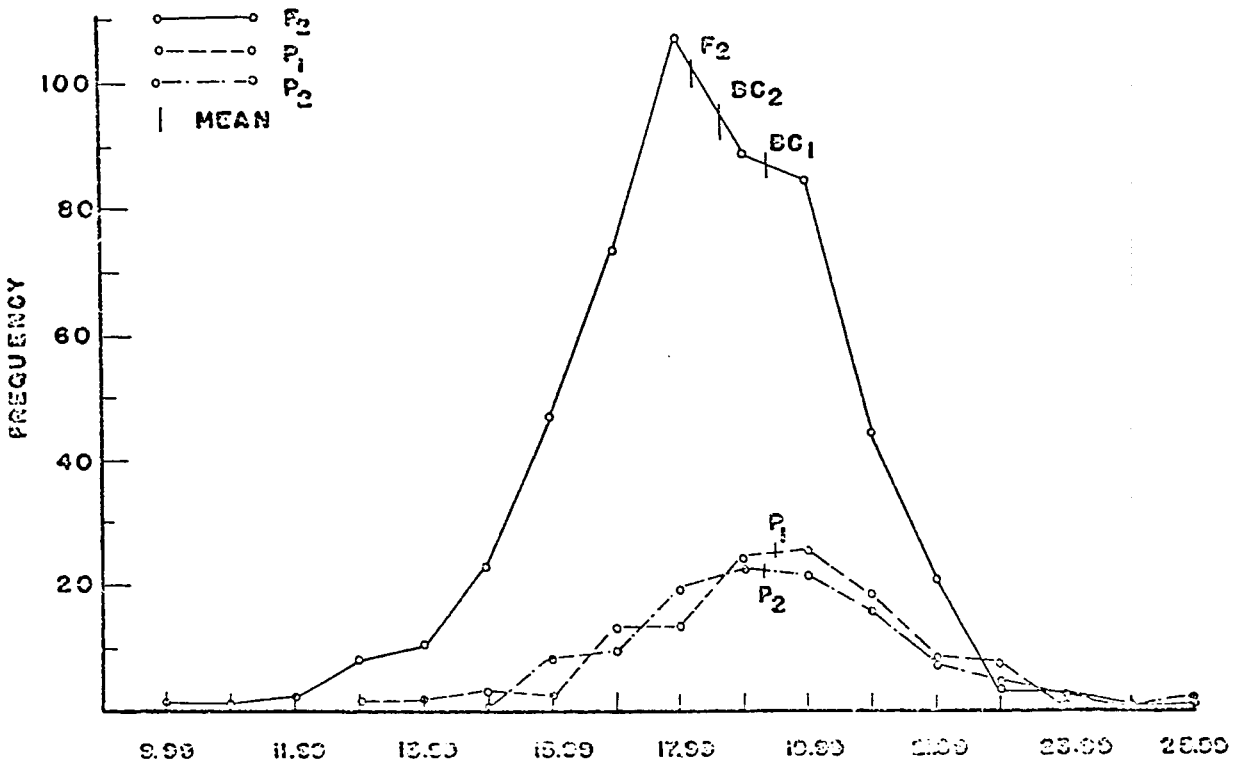


FIG. 7: FREQUENCY DISTRIBUTIONS FOR NUMBER OF SPIKELETS PER SPIKE IN P_1, P_2 AND F_2 POPULATIONS OF CROSS I, 1976-1977.

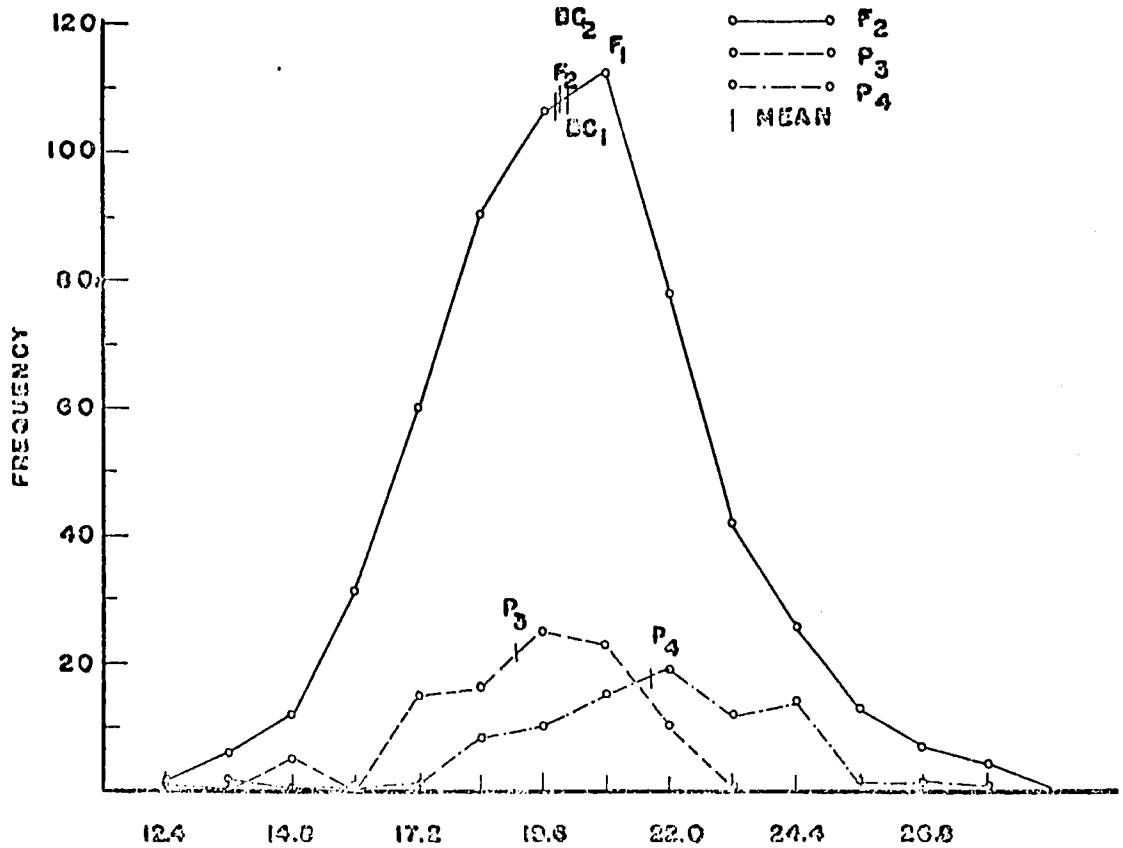


FIG.8: FREQUENCY DISTRIBUTIONS FOR NUMBER OF SPIKELETS PER SPIKE IN P_3, P_4 AND F_2 POPULATIONS OF CROSS II, 1976-1977.

Heritability estimates were highest under the high nitrogen level. The F_3 lines were genetically different.

These results are generally in accordance with those of several workers (Johnson et al. (1966), Kaltsikes and Lee (1971), Sun et al. (1972), Walton (1972), and Ketata et al. (1976a)).

Grain protein content--Grain protein content varied insignificantly in the four parents. However, the differences due to nitrogen effect were quite large. Low nitrogen led to about 5% reduction in grain protein from that of the high nitrogen level. In spite of the insignificant parental differences, F_3 means differed significantly under both nitrogen levels. The F_3 coefficient of variation ranged from 1.4 to 6.6%. Broad sense heritability of grain protein varied between 45.0 and 84.4%. High nitrogen level led to higher heritability estimates.

Several workers confirmed the relatively high degree of heritability of grain protein. High protein was reported by Johnson et al. (1969) to be a heritable genetic trait that can be readily transferred from one variety to another. The authors added that high protein can be achieved without reduction in grain yield. The high heritability level of protein content was supported by Davies (1960), Kivi (1969), Ali (1970, 1976), Edwards et al. (1976), and Shalaby (1977).

Interrelationships between traits--Besides the genetic studies of the five major yield components and protein content, the interrelations between these characters were studied. Correlation studies indicated highly significant correlations between heading date and plant height and number of spikelets per spike suggesting that selection for late heading would be accompanied by taller plants and more spikelets per spike. These results support similar findings of other workers under Egyptian conditions such as El Ghawas and Ballal (1966), as well as workers elsewhere (Schlehuber et al. (1967) and Chowdhry et al. (1970)).

On the other hand, our data indicated that heading date was negatively correlated with kernel weight, indicating an increase in kernel weight with selection for early heading. Weibel (1956), Sethi and Singh (1972), and Bhatt (1973) reported similar findings. These results suggest that the breeder can select for early heading without reduction in kernel weight which is a major yield component.

Correlation coefficients were positive and highly significant between plant height and spike length and number of spikelets per spike. This suggests that selection for taller plants would be accompanied by higher plant yields. These findings were similar to those of Selim (1960), El Ghawas and Ballal (1966), Barriga (1974), Somro and Aksel (1975), and Wicht (1976).

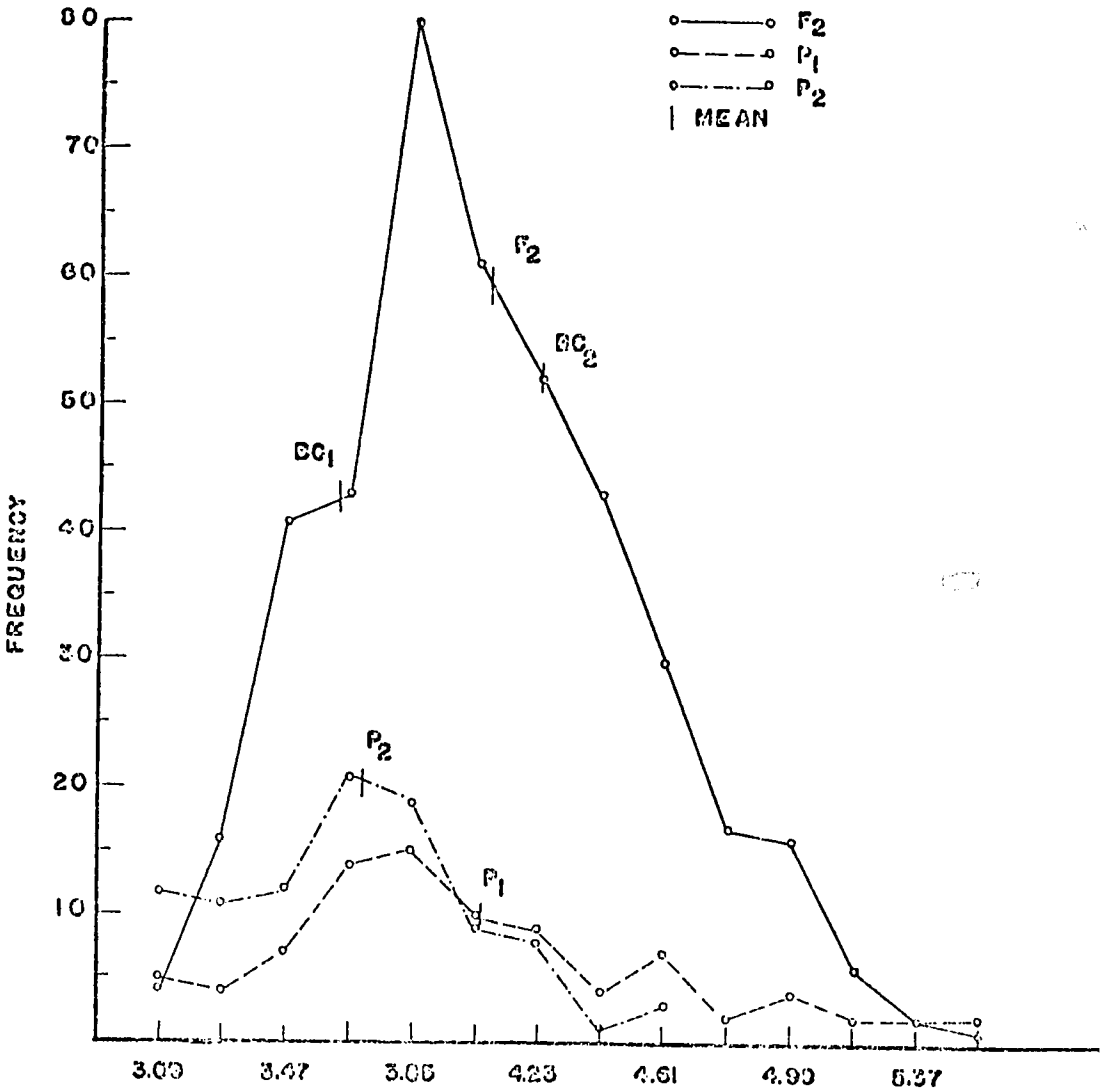


FIG.9: FREQUENCY DISTRIBUTIONS FOR KERNEL WEIGHT IN P_1, P_2 AND F_2 POPULATION OF CROSS I, 1976-1977.

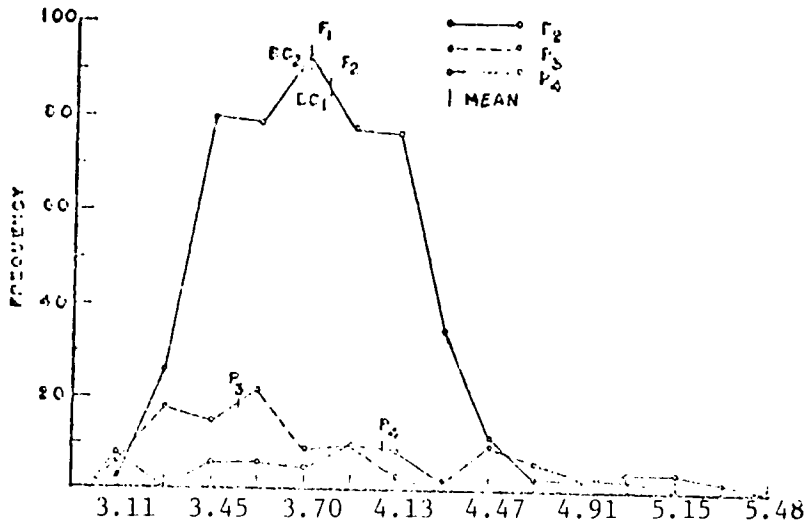


Fig. 10. FREQUENCY DISTRIBUTIONS FOR KERNEL WEIGHT IN P_3, P_4, and F_2 POPULATIONS OF CROSS II, 1976-1977.

On the other hand, plant height was negatively correlated with kernel weight and grain protein content in one of the two crosses, indicating that selection for taller plants would result in light kernels with lower protein content. The breeder should be careful while selecting tall plants. This is extremely important in Egypt where the dominating cultivars are rather tall.

Also, our data indicated negative correlation between number of spikelets per spike and kernel weight indicating that selection for more spikelets may result in lighter kernels.

Kernel weight was negatively correlated with grain protein. This was supported by Gill and Brar (1973).

Literature Cited

1. Albrecht, B. 1976. Studies on the heritability of culm length and other characters in winter wheat. Tagungshericht, Akademie der Landwirtschaftswissenchaften 143:95-103. (C.F. Plant Breed. Abstr. 47:6252, 1977).

2. Ali, M. I. 1970. Behavior of protein content and other agronomic characters in some vulgare wheat crosses. Ph.D. Thesis, Univ. of Alexandria, Alexandria, Egypt.

3. Ali, M. I. 1976. Inheritance of protein content and protein yield, and their relationships to other characters in common wheat. Meld. Norg. Landbr. Hogsk. Vol. 55, N.R. 18.

4. Barriga, B. P. 1974. Analysis of cause and effect for yield and yield components in spring wheat. Agr. Surv. 2:1-5. (C.F. Plant Breed. Abstr. 45:2599, 1975).

5. Bhatt, G. M. 1972. Inheritance of heading date, plant height and kernel weight in two spring wheat crosses. Crop Sci. 12:95-98.

6. Bhatt, G. M. 1973. Significance of path coefficient analysis in determining the nature of character association. Euphytica 22:338-343.

7. Chowdhry, B. S., Panwar, and B. V. Singh. 1970. Correlation of some important characters in wheat. Madras Agric. J. 57: 36-38. (C.F. Plant Breed. Abstr. 41:843, 1971).

8. Davis, W. K., Middleton, and T. T. Herbert. 1961. Inheritance of protein, texture, and yield in wheat. Crop Sci. 1:235-238.

9. Edwards, L. H., H. Ketata, and E. L. Smith. 1976. Gene action of heading date, plant height, and other characters in two winter wheat crosses. Crop Sci. 16:275-277.

10. El-Ghawas, M. I. and M. S. I. El-Ballal. 1966. An analysis of components of plant and spike yield variation in wheat. Annals of Agric. Sci., Fac. of Agric., Ain Shams Univ., Cairo, Vol. II:109-128.

11. Fonseca, Santiago, and Fred L. Patterson. 1968. Yield components heritabilities and interrelationships in winter wheat (Triticum aestivum L.). Crop Sci. 8:614-617.

12. Frey, K. J. 1954. Inheritance and heritability of heading date in barley. Agron. J. 46:226-228.

13. Frey, K. J. and T. Horner. 1955. Comparison of actual and predicted gains in barley selection experiments. Agron. J. 49:186-188.

14. Gill, K. S. and G. S. Brar. 1973. Genetic analysis of grain protein and its relationship with some economic traits in wheat. Indian J. Agric. Sci. 43:173-176. (C.F. Plant Breed. Abstr. 44:5057, 1974).

15. Jogi, B. S. 1956. The inheritance of agronomic and disease reaction characteristics in two barley crosses. Agron. J. 48:293-295.

16. Johnson, G. R. and K. J. Frey. 1967. Heritabilities of quantitative attributes of oats (Avena sp.) at varying levels of environmental stress. Crop Sci. 7:43-46.

17. Johnson, V. A., K. J. Biever, A. Haunold, and J. W. Schmidt. 1966. Inheritance of plant height, yield of grain, and other plant and seed characteristics in a cross of hard red winter wheat (T. aestivum L.). Crop Sci. 6:336-338.

18. Johnson, V. A., P. J. Mattern, and J. W. Schmidt. 1969. Research for high protein wheat. A report for the Agency for International Development.

19. Kaltsikes, P. J. and J. Lee. 1971. Quantitative inheritance in durum wheat. Can. J. Genet. Cytol. 13:210-218.

20. Ketata, H., L. H. Edwards, and E. L. Smith. 1976a. Inheritance of eight agronomic characters in a winter wheat cross. Crop Sci. 16:19-22.

21. Ketata, H., E. L. Smith, L. H. Edwards, and R. W. McNew. 1976b. Detection of epistatic, additive and dominance variation in winter wheat. Crop Sci. 16:1-4.

22. Kivi, E. L. 1969. Variation of protein in a breeding material of spring wheat. Peat. Pl. News, Helsinki, 2: 15-19. (C.F. Plant Breed. Abstr. 40:553, 1970).

23. Petr, F. C. and K. J. Frey. 1966. Genotypic correlations, dominance and heritability of quantitative characters in oats. Crop Sci. 6:259-262.

24. Rana, R. K., R. K. Singh, and V. P. Singh. 1973. Variability and heritability of yield and related characters in wheat. Haryana Agric. Univ. J. Res. 3:166-170. (C.F. Plant Breed. Abstr. 45:1928, 1975).

25. Schlehuber, A. M., D. C. Abbott, B. R. Jackson, and B. C. Curtis. 1967. Correlated inheritance of maturity and quality factors in a hard red winter wheat cross. Crop Sci. 7:13-16.

26. Selim, A. K. A. 1960. Quantitative inheritance in some wheat crosses. Annals of Agric. Sci. 5:87-110.

27. Sethi, G. S. and H. B. Singh. 1972. Interrelationships of quantitative traits with grain yield in triticale. Indian J. Agric. Res. 42:281-285.

28. Shalaby, E. E. 1977. Variability and correlation studies on common wheat, T. aestivum L. M.S. Thesis, Univ. of Alex., Alexandria, Egypt.

29. Soomro, B. A. and R. Aksel. 1975. Correlation and principal factor analysis of some characters in five-parent diallel crosses of common wheat. Egypt J. Genet. Cytol. 4:137-152.

30. Sun, P. L. F., H. L. Shands, and R. A. Forsberg. 1972. Inheritance of kernel weight in six spring wheat crosses. Crop Sci. 12:1-5.

31. Tikka, S. B. S., S. N. Jainini, and S. N. Coyal. 1973. Variability studies in wheat under Barani conditions. Science and Culture 39:29-130. (C.F. Plant Breed. Abstr. 44:1528, 1974).

32. Walton, P. D. 1972. A quantitative inheritance of yield and associated factors in spring wheat. Euphytica 21:553-556.

33. Weibel, D. E. 1956. Inheritance of quantitative characters in wheat. Iowa Sta. Coll. J. Sci. 30:451.

34. Witch, E. 1974. Correlation studies on wheat material of different plant height. Akademie Landwirtschaftswissenschaften 127:33-42. (C.F. Plant Breed. Abstr. 46:2261, 1976).

WHEAT BREEDING FOR RESISTANCE TO EYESPOT (CERCOSPORELLA HERPOTRICHOIDES FRON.) AT GEMBLOUX, BELGIUM

J. Vandam, L. DeFosse, and J. Raepsaet
Belgium

Introduction

Cercosporella herpotrichoides Fron., responsible for eyespot, a dreadful disease of wheat and barley, causes necrosis at the first internode of the stem.

The damage, observed at the end of the vegetation, is lodging of the cereal stems arising from the effect of wind, rain or from weight of the ear. Eyespot is a disease of great economic importance in countries with a humid temperate climate where wheat and barley are used intensively in the rotation.

Succession of wheat after itself or after barley is the most favorable condition for the disease extension; nevertheless, some other agricultural practices such as time and density of sowing, manure -- are not negligible.

Chemical fight against the disease was developed and systemic fungicides provide a means of reducing eyespot. However, the risks of soil pollution and the economical profit of these treatments are not yet fully determined.

Breeding for resistance of wheat to Cercosporella herpotrichoides has made considerable progress during the last years. The most cultivated wheat varieties and various species of the Triticum genus were tested for their susceptibility (Macer, 1966; DeFosse and Vandam, 1968). More resistant lines were created by introducing genes of Aegilops ventricosa into the Triticum aestivum genotype (Maia, 1967). The French winter wheat cultivar 'Roazon' is the result of such work (Dosba and Doussinault, 1978).

A more elaborate study was undertaken at Gembloux, following a breeding scheme dealing with two lines of T. aethiopicum, which involved testing of genus and species genetically related to the cultivated wheats.

Search for Sources of Resistance

Testing for disease resistance. Wheat plants were inoculated by Macer's technique (1966). Seedlings grown in small pots were inoculated by placing a cylinder of inoculated straw over the emerging coleoptiles. The pot was then fitted with humid sand to cover the cylinders. The lesions were perceptible about 50-60 days

Agricultural Research Center, Gembloux.

after inoculation. Infection was assessed on a scale related to the numbers of leaf-sheaths infected or penetrated by the pathogen (Scott, 1971).

Results. About 60 strains from our collection belonging to species of Triticum different from T. aestivum were tested. Among them, two tetraploid wheats gave a favorable response to the eyespot resistance test. These results could be related to the presence of red pigment on the leaf-sheath. The varieties are T. dicoccoides var. namuricum and T. dicoccum var. melanurum.

A group of 54 strains of 19 species of Aegilops were subsequently tested (Vandam and DeFosse, 1974). Observed results confirmed Ae. ventricosa as a source of resistance against eyespot. Ae. squarrosa has a fairly good reaction, although it was more susceptible than Ae. ventricosa.

The hexaploid line, V.P.M.1, obtained in France from Ae. ventricosa (Maia, 1967) has often been tested. It has outstanding resistance and only Ae. ventricosa and rye are superior to it.

A few substitution or translocation lines derived from the rye were observed (Vandam, 1976). None of this material gave resistance similar to the rye. Therefore, it seems that rye genes present in these lines are not the ones responsible for the high eyespot resistance of rye. On the other hand, a strain of Triticale, obtained at Gembloux, gave a favorable reaction.

Production of Varieties with Improved Resistance

Breeding scheme. In 1968, two crosses were made between a strain of T. dicoccoides var. namuricum and a strain of T. dicoccum var. melanurum with the Belgian wheat cultivar 'Cama'. The breeding work following the crosses is summarized. It should be emphasized that all our observations were compared with those on 'Cappelle Desprez', a fairly tolerant cultivar.

1968: Cross T. dicoccoides var. namuricum x Cama and T. dicoccum var. melanurum x Cama.

1968-69: Production of the two F_1s.

1969-70: Testing in a glasshouse (mean temperature approximately 12°) in very high humidity, of 1000 F_2 plants of each cross following the technique of inoculation and observation as described. Picking in the fields about 40 plants superior to Cappelle Desprez. Selecting the ten most interesting plants for agronomic characters (height of straw, general health, type of spike, etc.). Second cross of these ten plants with Cama from the two hybrids.

1970-71: Production of F_1s.

1971-72: Managing the F_2 as in 1969-1970. 10 selected plants again were crossed with Cama, for the two hybrids.

1972-73 and subsequently: Classical genealogic selection with elimination in the F_2 of the most susceptible plants to *Cercosporella herpotrichoides*.

Results

From 1976 tests of the susceptibility of several lines descended from the hybrids were made at the seedling stage. The experiments consisted of individual plots of five plants replicated fifteen times in randomized blocks. All the plants were grown in an illuminated growth cabinet (10° during 10 h. day, 8° at night). Control varieties were the parents of the crosses and the cultivars Cappelle Desprez (fairly tolerant), Holdfast (very susceptible) and the very resistant V.P.M.1.

Results are presented in Table 1.

From the offspring of the cross with *T. dicoccoides var. namuricum* (H. 1196) 17 lines were selected and tested in 1976. Seven were significantly less affected ($P < 0.01$) by the fungus than Cappelle-Desprez and not different from V.P.M.1.

In 1977 11 of the better lines from the preceding test were again observed. Among the seven best lines from 1976, the superiority of five was confirmed.

Among 10 lines from the offspring of the cross with *T. dicoccum* var. melanurum (H. 1197), only one (nr 5) was significantly better in 1976. Replication in 1977 of the 7 best lines showed that no one of them was different from the parent line. It should be reported that, in 1977, an important loss of virulence was noted in our isolate of *Cercosporella herpotrichoides*. A new isolate was subsequently used in 1978.

In 1979 the four best lines of H. 1196 were again tested with the new isolate of *Cercosporella herpotrichoides*. Several lines of the preceding test had been discarded because of their susceptibility to yellow rust in the fields. These four lines confirmed their superiority over the parent lines and over Cappelle Desprez but they were inferior to V.P.M.1. One line of the H. 1197 had a similar behavior.

In 1980 new experiments confirmed the superiority of this material against four new isolates of eyespot. The results are presently being analyzed. We can conclude that these lines represent significant improvement in resistance against eyespot. Their superiority over the parent lines seems to be caused by a transgression of resistance. Cytological analysis of this material showed no chromosomal abnormalities. They have been included in variety trials to test their agronomic characters in the fields. Although they have normal height of straw, they are very susceptible to physiological lodging owing a lack of straw stiffness. Their yield may be depressed for that reason.

Table 1. Results of tests of susceptibility to *Cercosporella herpotrichoides*.

H. 1176 *T. dicoccoides* var. namuricum x Cama[3]

lines		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
c.p.[1/]	1976:	3.3	3.9	3.1	4.7	4.6	3.6	3.5	3.6	4.7	4.1	2.8	4.8	3.9	4.7	5.0	3.7	5.3
	1977:	0.7	0.8	1.0	-	1.4	0.9	2.1	0.9	-	1.3	0.3	-	2.2	-	-	1.5	-
	1979:	3.5	-	3.4	-	-	3.5	-	-	-	-	3.7	-	-	-	-	-	-

H. 1177 *T. dicoccum* var. melanurum x Cama[3]

lines		1	2	3	4	5	6	7	8	9	10
c.p.	1976:	4.0	4.0	4.6	3.9	4.0	2.9	5.0	5.0	4.3	5.0
	1977:	0.9	1.3	-	0.5	1.2	1.4	1.1	0.8	-	-
	1979:	-	-	-	-	-	3.7	-	-	-	-

Control varieties

		T. dicoccoides v. namuricum	*T. dicoccum* v. melanurum	Cama	Cappelle Desprez	Holdfast	V.P.M.1
c.p.	1976:	5.5	6.6	5.8	6.2	7.3	2.5
	1977:	2.4	3.3	2.3	2.8	4.1	0.4
	1979:	4.7	5.6	6.7	5.5	7.1	1.9

[1/] c.p. = coefficient of penetration: number of leaf-sheaths infected or penetrated by the fungus divided by the number of diseased plants.

Current Programme and Prospects for Future

Our material is now included in new field tests of susceptibility to Cercosporella herpotrichoides in the adult stage under artificial infection by an appropriate technique (Bruhl and Nelson, 1966). These tests are necessary to confirm the results in the seedling stage. Seedling tests may indeed give an incomplete impression of the reaction to Cercosporella herpotrichoides because only the resistance of the leaf-sheaths is estimated. Although this factor is often prevalent, other elements also are of great importance and influence the probability of plant infection and resistance of stems to the attack (Doussinault, 1973). If these lines confirm their good resistance to the eyespot disease, they will be utilized as starting material in a recurrent selection scheme.

Acknowledgement

We are indebted to Dr. J. M. Jacquemin for the translation of this paper.

References

Bruehl, G. W. and W. L. Nelson. 1964. Techniques for mass inoculations of winter wheat in the field with Cercosporella herpotrichoides. Plant Dis. Rep. 48 (11):863-864.

DeFosse, L. and J. Vandam. 1968. La sensibilité du genre Triticum au Cercosporella herpotrichoides Fron. (I) Bull. Rech. Agron. Gembloux, N.S. 3(1):36-54.

DeFosse, L. and J. Vandam. 1969. La sensibilité du genre Triticum au Cercosporella herpotrichoides Fron. (II) Bull. Rech. Agron. Gembloux. N.S. 4(3-4):411-419.

Dosba, F. and G. Doussinault. 1978. Création de blés présentant les caractéristiques agronomiques favorables d'Aegilops ventricosa. Ann. Amélior. Plant. 28(1):27-44.

Doussinault, G. 1973. Comportement de 12 variétés de blé tendre vis-á-vis du piétin-verse (Cercosporella herpotrichoides Fron). Conséquences pour la sélection. Ann. Amélior. Plant. 23(4): 333-346.

Kimber, G. 1967. The incorporation of the resistance of Aegilops ventricosa to Cercosporella herpotrichoides into Triticum aestivum. J. Agric. Sci. 68(3):373-376.

Macer, R. C. F. 1966. Resistance to eyespot disease (Cercosporella herpotrichoides Fron) determined by a seedling test in some forms of Triticum, Aegilops, Secale and Hordeum. J. Agric. Sci. 67(3): 389-396.

Maia, N. 1967. Obtention de blés tendres résistants au piétin-verse par croisements interspécifiques. C. R. Acad. Agric. Fr. 53:149-154.

Scott, P. R. 1971. The effect of temperature on eyespot (Cercosporella herpotrichoides) in wheat seedlings. Ann. Appl. Biol. 68:169-175.

Vandam, J. 1976. Recherche de facteurs génétiques susceptibles d'accroître la résistance du blé tendre à Cercosporella herpotrichoides Fron. Actes du 94e Congres de l'A.F.A.S. Bruxelles Comm. no. 1711, 9 p.

Vandam, J. and L. DeFosse. 1971. Sensibilité du genre Triticum au Cercosporella herpotrichoides Fron. Proc. Meeting of Eucarpia, Dijon 1970:259-269.

Vandam, J. and L. DeFosse. 1974. Observations sur la sensibilité d'une collection d'Aegilops sp. à Cercosporella herpotrichoides Fron, agent du piétin-verse. Parasitica 30(2):58-62.

SOIL FERTILITY MANAGEMENT UNDER RAINFED WHEAT PRODUCTION -- OPPORTUNITIES AND CONSTRAINTS

R. A. Olson
United States

Abstract

Conventional principles of effective soil fertility management are considerably modified when the dry regions in which much of the world's wheat crop is produced are under consideration. Here fertilizers must be used judiciously in accomplishing most economic returns while alleviating the hazard of overstimulation. Timing and rate of N especially must be adjusted to soil moisture availability and to any existing mineral N in the soil rooting zone, while placement is a prime consideration with P. The practice of fallowing in the dryfarming regions significantly reduces fertilizer requirement of the wheat crop compared with continuous cropping.

Department of Agronomy, University of Nebraska

Wheat is one of the best adapted among the world's important food crops to growth under limited moisture conditions. As a result a major portion of the international arable area devoted to the crop's production is located in semiarid regions receiving less than 40 cm total annual precipitation. Availability of moisture has always been considered the primary limitation to effective production in these drier regions. Summer fallowing for a year has become common practice in these areas for supplementing the meager precipitation of the production year. Although the fallow period has normally accomplished the soil storage of only 20% or less of the rainfall received by the methodology employed until very recent times, that small increment has made the difference between essentially no yield and an economic crop. Soil fertility needs have been secondary to the moisture problem under these dry farming conditions, and the response to fertilizers has been much less pronounced than with crop production under irrigation or more humid climate. The reason is explained in part by the fallow practice in itself which is responsible for an extra year's mineralization of nutrients from native soil organic and mineral sources.

With increasing rainfall into the sub-humid climatic category, wheat remains as an important crop but usually superceded by maize, rice or root crop which require a more favorable moisture regime. Fallowing is rarely practiced where annual precipitation exceeds 50 cm and rather continuous annual cropping is the rule, even multiple cropping with the more humid situations. Under these conditions crop nutrient needs are accentuated and response to fertilizer treatments are more certain.

With ever higher yields coming from improvements in varieties of wheat and in tillage methodologies for moisture conservation (Figure 1) together with further passage of time for depletion of soil nutrients has come increasing recognition in recent years of nutrient shortages for optimum production of the rainfed wheat crop world around. Because of the need for balancing the moisture available against nutrient supply much greater care must be exercised in fertilizer management in the dry regions than is needed under more favorable moisture conditions.

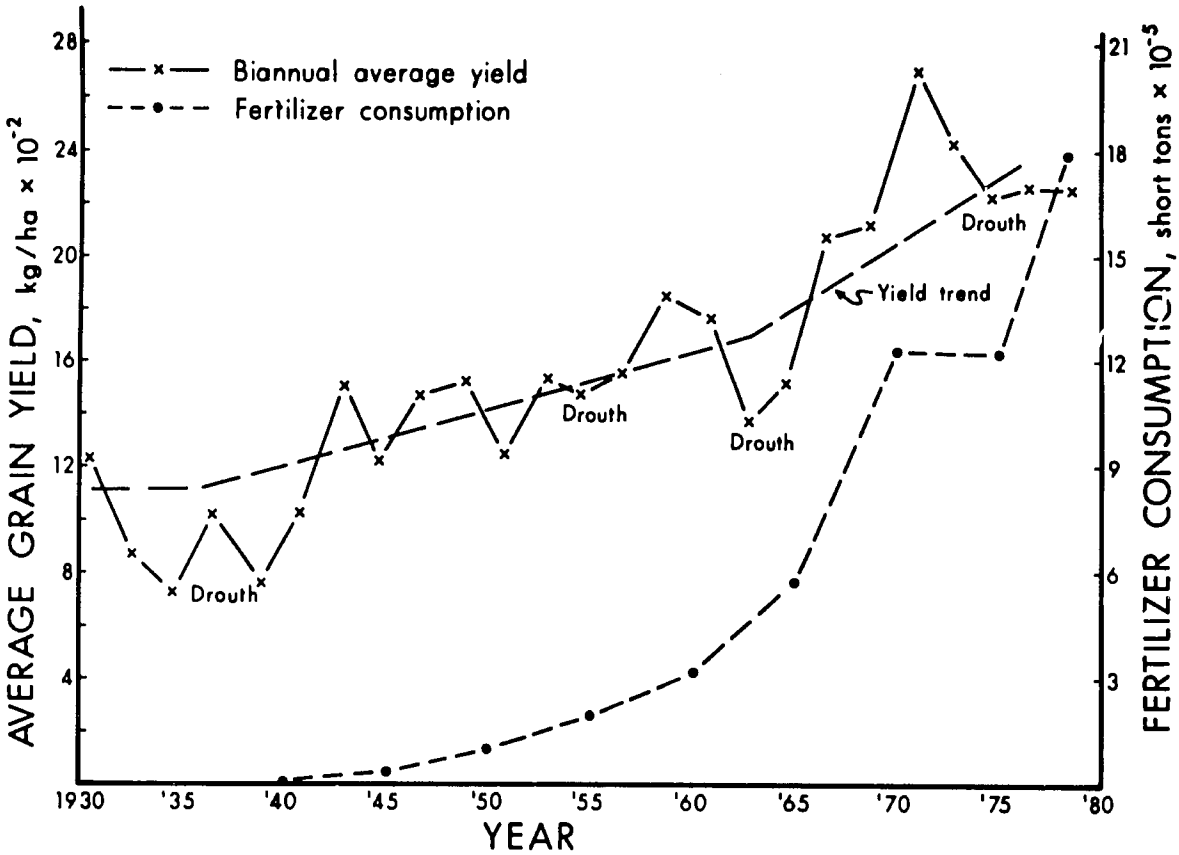


Figure 1. The relation between fertilizer consumption in Nebraska and average yields of winter wheat during the past 50 years.

Nutrients Required and Their Prescription

A relatively small number of the 16 elements known to be essential for crop growth has been found limiting for optimum growth of wheat in the drier regions of the world. The generally temperate climate in wheat-producing countries combined with the restricted rainfall has been responsible for limited weathering of the native rock materials from which soils have formed and little leaching of the released soluble products of that weathering has occurred. Thus most of the alkaline earth and metallic elements of plant nutrition are normally plentiful in the soil even after hundreds of years of cropping, and it is primarily N and P that require attention. Locally Zn has been found deficient, especially associated with highly calcareous soil materials, S in sandy soils of low organic matter content, and K in sandy soils and in the more humid regions of wheat production where soils are acid in reaction. Important as these exceptions are to the farmer where shortage exists, the areal extent is small compared with that for N and P, and accordingly, the primary focus of this paper will be on the latter two elements and their management. Well recognized is the fact that deficiencies of certain of the secondary and micro nutrients are being recognized increasingly with the higher yields made possible by improved genotypes fertilized liberally with the macro nutrients. The production of very high analysis inorganic fertilizers devoid of nutrient impurities of previous fertilizer sources has contributed to the growing need for those elements.

Conducting a series of field trials and summarizing the responses obtained has been one of the more commonly employed procedures for specifying the nutrient(s) needed in a given region and the rates required for most economic production. The method obviously does not compensate for the exceptional soil condition, better or poorer than average, and becomes less and less meaningful after years of differential fertilizer use by farmers of the region. It designates the average condition but not the case of the individual farmer.

Prescription of the kind and amount of nutrient(s) needed can be achieved more effectively by soil testing than by any other technique presently available to the producer. It perhaps goes without saying that soil testing can have no scientific basis until such time as the testing procedures employed have been correlated with plant response on soils of the area and have ultimately been calibrated with yield response data from many field experiments having fertilizer rate variables. Such trials must be made for all the major crops of the area since different calibration ranges are likely to exist for each.

One aspect of soil testing that has not yet received sufficient attention is the depth to which soils should be sampled for most reliable prediction purposes. Wheat growing on those soils having copious quantities of a given nutrient in the lower part of the crop rooting zone will not require as much, if any, of that nutrient at a specified soil test level of the surface soil as when grown on other soils without that deep subsoil reserve. Such deep sampling is particularly

necessary for the mobile nutrients N and S but is important to varying degree for all other nutrients as well (Figure 2).

Effective soil testing will reveal other limitations that may exist to good plant growth on the soil. In the more humid regions where soils are acid a major limitation may be due to the toxicity of excessive exchangeable Al and Mn on the soil which can be corrected by an appropriate lime application. Not to be overlooked in this respect is the charge that has been given to wheat breeders to develop varieties with increased tolerance to Al toxicity which could be less difficult and cost much less than correcting the malady in the vast areas of soils in the tropics and subtropics where it exists (5). Where rainfall is quite limited the problems of salinity and sodic soil may restrict production. Fertilizer treatments are not likely to afford good responses under these conditions until correction has been effected, one exception being the alleviation of Al toxicity accomplished by P fertilization.

Nutrient Response Determinants

Genotype

Effective crop response to applied fertilizer is heavily dependent on the genetic potential of the variety planted for high yield. Thus, the optimum rate of N for new dwarf varieties of fall-planted spring wheat grown under irrigation in India as reported by Wright (29) was 120 kg/ha in contrast with approximately 40 kg/ha for traditional tall varieties, grain yield leveling off around 4300 kg/ha with the former and 3500 with the latter.

The three-year study in Nebraska of Table 1 comparing four contemporary varieties in use by farmers at the time gives further evidence of the significant influence genotype can have on fertilizer response (2). Scout and Lancer, the more recently released varieties in this group, yielded slightly more than the other two without fertilizer treatment but substantially more with the optimum 45 + 11 + 0 application. Value/cost ratio for the optimum fertilizer treatment at that time was 3.0 for the Scout variety, but only 2.3 for Omaha and Ottowa.

Moisture Availability

A sufficient moisture supply for producing a good crop yield is the first requisite to efficient fertilizer practice. Although judicious fertilizer use will enhance crop water use efficiency, there is no way that fertilizer can substitute for water. It is difficult if not impossible to specify an amount of annual rainfall below which the fertilization of wheat is unlikely to prove economic. Nature of the rainfall as to intensity and its timeliness in relation to seasonal crop demand determine its effectiveness and thereby the total amount required for crop growth.

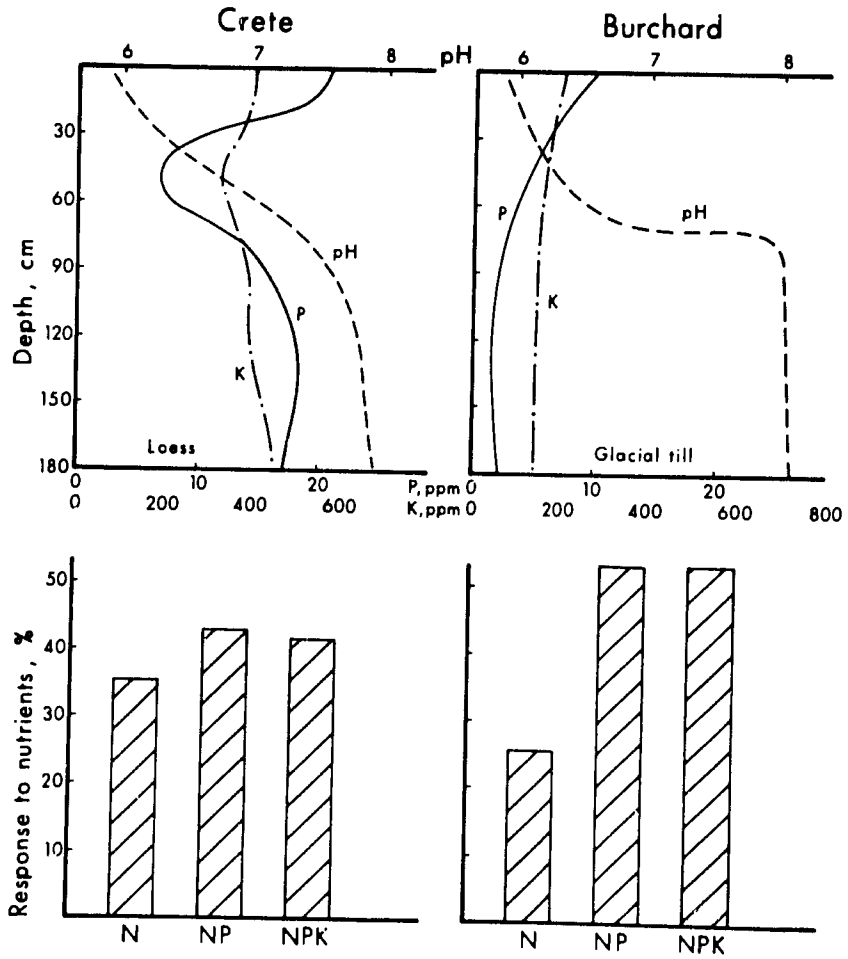


Figure 2. Chemical properties of the profile of two Nebraska soils and wheat yield response to applied nutrients on these soils (ave. for 7 field experiments on Burchard, 22 on Crete).

Table 1. Influence of optimum fertilizer treatment on yield response of four winter wheat varieties in Nebraska, 1964-66.

Variety	Fertilizer treatment N+P+K	1964 yield Ave. 2 expts	1965 yield Ave. 2 expts	1966 yield Ave. 2 expts	3-year average Grain yield	3-year average V/C[1]
	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	
Scout	0+0+0	2498	1013	2430	1958	-
	45+11+0	3240	1958	2565	2565	3.0
Lancer	0+0+0	2565	1080	2295	1958	-
	45+11+0	2970	2025	2565	2498	2.5
Omaha	0+0+0	2025	945	2093	1688	-
	45+11+0	2498	1485	2295	2160	2.3
Ottowa	0+0+0	2093	945	2228	1755	-
	45+11+0	2925	1553	2430	2228	2.3

[1] V/C = Value of increased grain yield from fertilizer treatment divided by cost of fertilizer.

The above limitation notwithstanding, it is interesting to note results of field trials of FAO with fertilizers on wheat in relation to rainfall received in the countries represented. During the 1961-77 interval some 250,000 fertilizer trials and demonstrations were conducted under the FFHC Fertilizer Program of FAO in 40 developing countries. Of this total about one-tenth were conducted on wheat, and as portrayed in Table 2 the average crop response to fertilizer was lowest in Morocco, Syria and Tunisia, three of the driest counties among those listed. Also apparent is the limited fertilizer response obtained throughout the Near East and North Africa region compared with the much more favorable response picture in the Far East where rainfall is notably more generous as the general rule. Farmers in the LDC's have been found to take up fertilizer use readily where value/cost ratio is demonstrated to exceed 2.0, but are dubious of the economic risk below that level.

Not only does moisture availability influence the magnitude of positive response to fertilizer, but it may as well portend the degree of negative response, i.e., yield depression from fertilizer. Where applied nutrients stimulate vegetative growth under conditions of limited moisture supply, the available water may be used up by the time the crop reaches the critical flowering and grain filling stages, with resulting yield reduction. The phenomenon has been observed as a progressive one especially with increasing rates of applied N in the drier regions (15).

Figure 3 gives evidence of the close relation that exists between seasonal rainfall and magnitude of fertilizer response from data acquired within the state of Nebraska. The increasing response with greater rainfall is not totally a reflection of moisture availability per se. Also involved is the fact that fallow-cropping (with twice the time for nutrient mineralization) is employed in the western area of least rainfall, the shorter period of time the western soils have been cropped, and the further fact of more highly weathered soils in the subhumid eastern part of the state with common requirement for more than N alone.

Soil Morphology

Where detailed soil classification information exists it is well established that crop response to fertilizer is closely related to the morphological characteristics expressed in the soil type (1, 17, 20). Soil texture is a major criterion with sandy horizons representing the minimum in nutrient storage capacity and the maximum accompanying those horizons high in clay mineral of 2:1 Si:Al ratio and high in organic matter content. Soil depth and the presence or absence of restrictive zones to root penetration have moisture storage implications as that factor relates to nutrient availability and further determine crop 'root room' for nutrient extraction. Other profile characteristics of extreme chemical or physical nature that adversely affect crop root activity also undermine the soil's quality as a provider of nutrients.

Table 2. Fertilizer trials on wheat under the FFHC Fertilizer Program of FAO, 1961-77.

Location	Trials and demonstrations	Ave. response of best treatment	
		Yield increase	Value/cost ratio
	No.	%	V/C
	Regional trials and demonstrations[1/]		
Near East & North Africa	22,865	60	2.3
Far East	533	171	4.8
	Country trials		
Afghanistan	638	294	4.1
Colombia	15	73	4.4
Ecuador	66	94	2.0
Ethiopia	52	74	3.6
Guatemala	48	166	3.5
Lebanon	87	98	3.0
Morocco	35	71	1.9
Nepal	365	180	3.1
Peru	124	102	4.5
Syria	46	36	1.0
Tunisia	28	39	1.8
Turkey	137	94	3.6

1/ Demonstrations had a minimum number of treatments included without replication, whereas trials contained rate variables of NPK with internal replication.

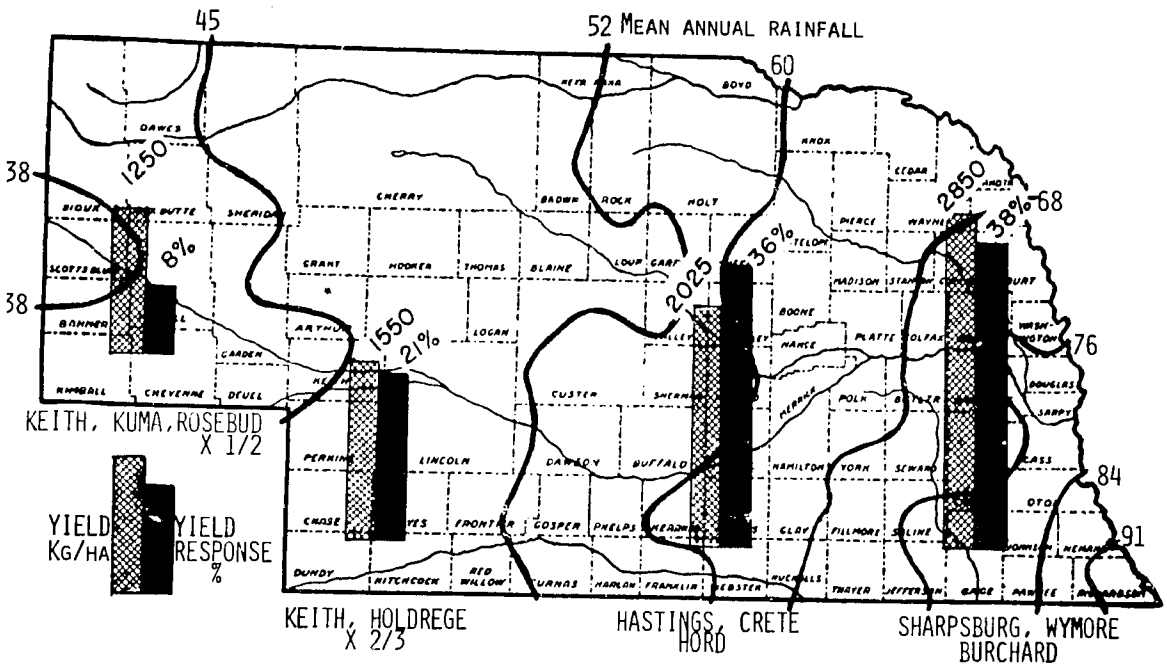


Figure 3. Average yields and yield response to applied fertilizer of winter wheat grown on major soils under the varied levels of mean annual rainfall in Nebraska (ave. for 21 experiments, 1971-73). Yields in Western Nebraska X½ because of alternate wheat-fallow, X 2/3 in SW Nebraska due to fallow one year in three.

Soil Nutrient Level

The quantity of available nutrient present in soil in consequence of pedogenic processes in the soil's development is a major determinant of crop response to applied nutrients. As a very general rule the bases among the essential elements of plant nutritions are plentiful in soils of the dry regions for satisfying plant needs even after hundreds of years of crop production without replenishment by fertilization. But these same soils, especially where calcareous, were probably deficient in P for top production from the very first days of cropping. At the same time, these dry region soils never accumulated much organic material during their development under the native vegetation and it is very likely that N was limiting for maximum yields obtainable under the existing environment shortly after cropping of the soils began.

The native nutrient levels of soils of the warmer, more humid regions present quite a different picture, however, with the more intensive weathering that occurred during soil formation soils were more thoroughly leached of the basic elements contained in the native rock materials from which they formed and were left acid in reaction to varying degree. Extensive areas of Brazil and elsewhere in South America, as an example, were endowed with the Cerrada soils which require lime and P as a first step for correcting Al toxicity in making grain crop production on them possible. Thus, Lopes (10) in Brazil reported 92% of 518 surface soil samples being more than 20% saturated with Al and 79% of the samples more than 40% Al saturated. Deficiencies of K, Mg, Ca, and Mo are notably more common the more humid the environment in which the soil is found.

In many places following several years of intensive use of inorganic fertilizer by farmers, the residuals in soils from prior fertilizer application have come to be the predominant factor controlling the current status of the major nutrients, N, P, and K in the soil system. Rarely is it possible for the crop to take up all of the nutrient applied in a given season, meaning that any of that not utilized and not lost through leaching or volatilization channels will build up a reserve in the root zone over several years of fertilizer practice and must eventually be taken into account in any good fertilizer program. Such accumulations with N are likely to be much more pronounced in the drier regions of wheat production than in the more humid regions with available P build up depending on the basic chemistry and mineralogy of the treated soil.

Soil and Crop Management

Practices in soil and crop management have a considerable bearing on crop response to applied nutrients. In the more humid environments where cropping sequences include a legume the accompanying symbiotic process reduces the quantities of fertilizer N required for optimum production but higher levels of certain other nutrients may be required to grow the legume effectively. Likewise wherever significant amounts of animal manures, sewage or other organic wastes are

returned to the soil the need for all nutritional elements is reduced. Liming of acid soils usually enhances the availability of N, Ca, Mg, Mo, S, sometimes P, but depresses that of B, Zn, Fe, and Mn. Tillage and residue management practices directed toward maintaining a residue mulch on the surface for conservation of soil, energy and moisture tend to accentuate fertilizer need because of the cooler soil temperature and phytotoxic effects of the residue. The first preceding crop to the one to be grown often has dominant influence on the latter's response to applied nutrients as explained by factors of nutrient and moisture depletion or soil structure effects.

Effective Fertilizer Management Practices

Nitrogen

Nitrogen is the most universally needed fertilizer nutrient for optimum production of wheat and the most difficult of all elements to control in the soil-plant system. It is subject to volatilization losses as NH_3 or as NO_x, to leaching losses as NO_3^-, and to microbial (organic) tie up depending on conditions of the soil environment, many of which are created or at least influenced by the management practices employed by the farmer. In consideration of the high cost of fertilizer N today and the potential that exists for environmental pollution with N, it is particularly important that the nutrient be used in the most efficient way possible.

Rate of N. Nitrogen is the most stimulating of all nutrients to vegetative growth of crops. Where short in supply the crop cannot reach its yield potential and where present in excess N can cause excessive and prolonged vegetative growth in most varieties resulting in tall, weak-stemmed plants that lodge readily. The prolonged vegetative phase in delaying maturity can be especially harmful if summer drouth occurs in the mid-latitudes or if early frost shortens the growing season in the northerly latitudes of wheat production, and can accentuate certain disease problems.

The foremost consideration in effective fertilizer N management is that of most economic rate of application. During the first few years of fertilizer N studies in the Great Plains of the U.S. it appeared that rate could be projected fairly well by past management and moisture availability. Twenty-two kg fertilizer N/ha for each seven cm of available moisture stored in the soil rooting profile at planting was proposed for continuously cropped land (22). After several years of fertilizer N use, however, it has become apparent that a dominant feature determining optimum rate for the crop to be grown is the amount of residual mineral N in the rooting profile remaining from prior fertilizer treatments (18). Wheat growing on continuously cropped land in a Nebraska region with 60-75 cm mean annual rainfall showed no response to applied N if residual NO_3-N in the 180-cm profile exceeded 90 kg/ha. On the other hand, yield response was still on the upgrade at a 67 kg N/ha rate when residual NO_3-N in the profile was less than 45 kg/ha. Fallow-wheat grown in a region of 40-60 cm rainfall was also ascending in yield at the 67 kg rate of N where residuals were less than 45 kg. Economic response

stopped at 45 kg N applied with 45-90 kg residual, at 22 kg N applied with 90-135 kg residual, and yield depression accompanied applied N when residuals exceeded 135 kg N/ha. Differences between the response curves of the two cropping systems are presumed to be explained by the higher nitrification potentials of the continuously cropped soils in eastern Nebraska with their higher organic matter contents.

The role of residual mineral N in controlling required rate of N for optimum yield of wheat is especially pertinent for the drier climatic regions of wheat production as in much of the Great Plains of the U.S. where little deep percolation losses of water occur. Experience with fertilizer N requirements of irrigated crops, however, indicates almost equal importance of the residual N component. On this basis we would project a need for surveying profile mineral N even in humid regions where wheat is grown on deep, medium to fine textured soils that are well drained.

Time of N Application. Winter wheat will commonly absorb in the order of 60 to 80 percent of its total above-ground N requirement between resumption of growth in the spring and the early heading stage (17, 28). It is thus possible for the crop to derive adequate N nutrition with limited quantities available in the fall if a plentiful supply is available to the root system during the grand period of growth.

Long term studies on time of N fertilization in the central Great Plains of the U.S. indicate fairly comparable results from spring and fall applications in most years from the standpoint of yield alone, both exceeding winter application (15). Spring topdressing does afford an opportunity to the grower for evaluating stand of crop and moisture available at a relatively late stage in the crop season in judging the probability of profitable response to N. It also precludes the possibility of excessive fall vegetative growth (with commensurate root rot and other disease problems) and excessive moisture use in years of protracted favorable growing conditions in the fall. Nebraska studies indicate, for example, that the likelihood of yield reduction from N use due to these factors is four times greater with fall application than with spring treatment. On occasion, however, poor results will accrue from spring treatment in the absence of rain for carrying the topdressed N into the root zone early enough for full yield expression.

Many regions of winter wheat production in the developing countries receiving spring rainfall would benefit from spring topdressing over planting time application of the required N. Potential losses of N to runoff, denitrification, leaching and ammonia volatilization are thereby minimized with further benefit of enhanced water utilization efficiency by the crop. Studies in the relatively cold, dry Prairie Provinces of Canada, for example, showed fall applications of N were usually not as efficient as spring treatments for wheat. One series of 20 field experiments in Alberta over a 4-year period revealed that fall applications were only 55% as effective as spring.

Measured losses by ^{15}N labeling were 41%, 30%, and 16% from KNO_3, urea and $(NH_4)_2SO_4$, respectively (11), attributed primarily to denitrification. Evidence for leaching loss by analyzing for $^{15}NO_3^-$ could not be found by sampling to the depth of 120 cm. The delayed treatment also reduces the possibility of overstimulation which is ever a hazard in dry farming regions.

Phosphorus

The soil in the drier regions of wheat production is normally alkaline in reaction and contains free lime in part if not all of the rooting profile. It is generally true that calcareous soils are inherently low in available P for the optimum growth of crops. Thus P proves to be essentially as great a limitation as N to world production of wheat, corroborated by the fact that average soil pH of sites in the IWWPN during 1976 was 7.6 with most locations being calcareous from the surface downward (9). Wheat is one of the most responsive crops to P fertilization with the critical level of soil P for the crop being approximately twice that for maize, three times for soybeans. The increasingly high cost for fertilizer P, the fact that world P resources are finite with nothing that can substitute for it in agriculture, and the potential role of applied P in environmental pollution require that the farmer use fertilizer P in a thoroughly judicious manner.

Rate of P Application. Fertilizer P is much less stimulative of vegetative growth than is N and, accordingly, rarely presents the overstimulation problem so commonly encountered with N in dry farming. In correcting a serious P deficiency fertilizer P treatment will induce added tillering and more vigorous plant growth, but does not foster excessive vegetative growth if substantially more than required is applied. Excessive rate thus becomes primarily an economic consideration, although in some situations may create disturbance with certain other elements in plant nutrition such as Zn and Fe.

The predominant factor determining optimum rate of fertilizer P for wheat is the level of soil solution P maintained in dynamic equilibrium with solid phase P in the rooting profile of soil. Lesser contributing factors include the soil drainage and temperature, the level of other soil nutrients, and the capacity of the soil being treated to revert added fertilizer P to less available forms. Heaviest rates are likely to be required with soils strongly acid in reaction containing a large portion of Fe and Al oxides in the clay fraction and on highly calcareous soils, especially where both are very low in organic matter content. Lowest requirement normally exists with soils only slightly acid in reaction, around pH 6.5, that possess at least a modest organic matter content and a significant quantity of apatite species among the native soil minerals.

Time of P Application. An adequate supply of readily available P in the soil is essential from the earliest growth stages for achieving top wheat yields. The element more than any other promotes tillering and the establishment of a comprehensive root system. A sturdy

root system established in the fall can make the difference between good and poor survival when severe winter weather conditions occur.

A second significant factor influencing time that P should be applied relates to mobility of the element in soil. With medium to fine textured soils P materials are for all practical purposes immobile necessitating placement in the rooting zone before crop root establishment. Significant movement within a given cropping season can be expected only in very sandy or organic soils. Thus, in consideration of the physiological factor elaborated above and this mobility factor, best results from fertilizer P applications can be expected only with applications made at or before planting time in most cases. In assisting crop establishment in the fall not only does the added P, when needed, alleviate winter killing but as well assists in providing better ground cover that will curb erosional processes during the winter and early spring months.

P placement. Duley (3) demonstrated a decided advantage for placing P fertilizer in the seed row of wheat at planting. Those early results of the 1920's gave indication of band placement being almost twice as effective as broadcast application of the P. Subsequent work in Kansas, Nebraska, Michigan and elsewhere in the U.S. have confirmed the superiority of row placement over a wide range of soil conditions. These findings have been responsible for recommendations to farmers of halving the P for wheat if row applied compared with broadcasting before final tillage. Circumstances have been encountered, however, where row and broadcast placements have given similar results, others where banding was as much as four times as effective. A number of factors can be responsible for this anomaly including availability of soil moisture, but apparently the predominant one is the level of available P in the soil. Work of Peterson et al. (21) showed that a ratio of 3 to 4:1 of required broadcast: row applied P existed with soils testing low in P while a 1:1 ratio was found with those soils of medium soil test P.

In many situations where row banding was proved superior, the explanation probably derives mainly from the three following factors. When present at the site of the germinating seed, the new seedling immediately has access to a highly enriched zone of P for absorption by its developing root system. Secondly, the fertilizer being placed in a concentrated band does not have the intimate contact with soil as when broadcast and thus is not subject to as rapid reversion reactions that reduce its solubility and availability to plants. A third factor benefitting band placement is the fact of its presence at some depth below the soil surface where the soil is less subject to evaporational drying in contrast with those broadcast particles that remain at or near the surface even after a disking operation. With much of the material thereby being in more continuously moist soil the opportunity for plant uptake is enhanced (17).

Potassium and Others

Responses to K and other plant nutrients have been few in the world's drier regions where most of the world's winter wheat is produced. Potassium is not removed from the soil in significant quantities with wheat production where the straw is left on the land, little K being present in the grain. This plus inherently high levels of exchangeable soil K largely account for the slow K depletion in the dry farming regions.

Sulfur shortage restricts wheat yields in local areas, especially on soils low in organic matter content and on acid, sandy soils. Zinc deficiency has been recognized locally, most commonly in calcareous soils of high pH. Where any of these shortages exist they are obviously of great significance to the farmers involved. Prediction of the problem can readily be made if well correlated and calibrated soil testing methods have been established and are available for the region.

Carriers of N and P

There are numerous chemical carriers of N and P manufactured by the fertilizer industry, but the several listed in Table 3 are either the most extensively marketed world around or are particularly adapted for use in specific soil regions. Among the carriers of N, the cheapest source is anhydrous ammonia, a carrier that requires considerable sophistication on the part of the farmer and the equipment for its use. Ammonium nitrate has the very desirable constitution of part NO_3^- that can disperse immediately with penetrating moisture throughout the crop root zone and part NH_4^+ that stays where placed for a period until changed by nitrification. Its high deliquescence presents problems in very humid situations and when mixed with organics it is explosive. Ammonium nitrate-lime overcomes the deliquescence problem and has the acidity induction factor compensated. This makes it a much more acceptable product for use in humid regions of inherently acid soils. Ammonium sulfate does not have the moisture absorbing problem of ammonium nitrate but is the most acidifying of all nitrogenous fertilizers. It is rather low in analysis and therewith has high shipping and storage costs associated but is especially useful for soils deficient in both N and S. Urea with its high analysis and generally non-innocuous properties is rapidly becoming preeminent in international commerce. If heated excessively in the final prilling process it may contain a portion of biuret which is very toxic to seedlings, and it is subject to potential NH_3 volatilization losses, expecially on alkaline soils. The UAN solutions are growing rapidly in popularity due to the ease of handling by pump and spigot. Considerable attention is being given to delayed release products including nitrification inhibitors at the present time which have primary application on readily leached sandy soils and with poorly drained soils. Since little of the world's wheat crop is grown under such soil conditions it is doubtful that much of these materials will ever be employed for the crop's production.

Table 3. Common chemical carriers of N and P, characteristics influencing their use, and relative effectiveness on acid and calcareous soils

Carrier and usual formula	Characteristics Influencing Use	Effectiveness for wheat 1/	
		Acid Soil	Calcareous Soil
	N Carriers		
Ammonium nitrate NH_4NO_3-33% N	Moderately acidifying; deliquescent; explosive	E	E
Ammonium nitrate lime $NH_4NO_3.CaCO_3$-16% N	Neutral; non-deliquescent	E	E
Ammonium Sulfate $(NH_4)_2SO_4$-21% N	Strongly acidifying; NH_3 volatilization potential alkaline soils	E	E
Urea $CO(NH_2)_2$-43-45% N	Mod. acidifying; deliquescent; NH_3 volatilization from surface of alkaline soils; toxicity of any biuret present	E	E
Anhydrous ammonia NH_3-82% N	Mod. acidifying; toxicity to germinating seeds; required pressure equipment; potential NH_3 volatilization depending depth x rate x soil texture & moisture x shank spacing; least expensive N source	E	E
UAN Solutions $CO(NH_2)_2$ and NH_4NO_3-28-32%N	As with two solid carriers above	E	E
Delayed release products Many kinds	All peculiar to the individual product	Var.	Var.
	P Carriers		
Diammonium phosphate $(NH_4)_2HPO_4$--18-46-0	Water soluble; toxicity to germinating seeds; mod. acidifying	S	G
Conc. superphosphate $Ca(H_2PO_4)_2$--0-45-0	Mod. water soluble; sl. acidifying	E	E
Monoammonium phosphate $NH_4H_2PO_4$--11-48-0	Water soluble; mod. acidifying	S	S
Nitric phosphates $Ca(NO_3)_2 \cdot CaHPO_4$--var. (among others)	Varied water solubility: If high If low	E G	G F
Calcium metaphosphate $Ca(PO_3)_2$--0-63-0	Water insoluble; sl. acidifying	E	F
Single superphosphate $CaHPO_4 \cdot Ca(H_2PO_4)_2 \cdot CaSO_4 \cdot 2H_2O$--0-21-0	Mod. water soluble; sl. acidifying	E	G
Basic slag Varied	Water insoluble; non-acidifying	F-G	P
Rock phosphate $3Ca_3(PO_4)_2 \cdot CaF_2$	Water insoluble; non-acidifying	P	V
Phosphoric acid	Acidifying; caustic		
ortho--0-54-0		E	S
super--0-79-0		E	S

1/ S = superior, E = excellent, G = good, F = fair, P = poor, V = essentially valueless, Var. = variable

A high rating has been given for all N carriers listed when used for wheat production. This is with the assumption that each material is used in a way to compensate for its own limitations. The most desirable material, accordingly, for any farmer's use will be governed by the cost per unit N of the materials available to him and the facilities which he possesses for utilizing them.

Decided interaction occurs between carrier of N and the time of application. The previous discussion on timing was made without reference to anhydrous ammonia. Because of the required injection at depth in soil it is virtually mandatory that this material be applied prior to planting. However, because of the depth that it needs to be placed, and its very limited mobility until nitrification occurs in the following spring, NH_3 acts more like a delayed release form of N and not greatly different from spring applied solid materials for the winter wheat crop.

Substantial variability exists in effectiveness of P carriers on the market and with a considerable interaction of soil character. The water soluble types are generally excellent for use on both acid and calcareous soils and are significantly enhanced by the presence of an associated NH_4^+ ion. Their superiority is manifest especially with band application near the seed row in contrast with broadcasting. Some carriers of relatively low water solubility like nitric phosphates, metaphosphate and basic slag will commonly give very good results when used on acid soils but are poor carriers for calcareous soils. Among those carriers listed as excellent the primary consideration by the grower should be the unit cost of nutrient contained.

Dual Placement

The term 'dual placement' has recently come into usage for designating the procedure of simultaneously placing anhydrous ammonia and phosphatic fertilizer in the same position in soil, usually before the crop is planted (13). The work reported shows a greater uptake of the fertilizer P than achieved by broadcasting before final tillage or by row placement at planting. If experience does prove this to be a superior practice across a range of soil conditions it can probably be explained by two factors. In the first place, the required depth of NH_3 placement means that the P will be in soil that is continuously more moist than where placed closer to the soil surface and thereby more continuously accessible to the growing crop. Secondly, a portion of the NH_3 will persist as NH_4^+ in the zone of P placement much longer than the small amount of NH_4^+ in a conventional starter fertilizer allowing the known benefit of NH_4^+ to fertilizer P uptake (11, 14) to carry through a greater portion of the growing season. An added advantage to NP treatment in this way is that it can be done as part of the primary tillage of a field by appendage to moldboard plow, chisel plow or sweep thereby reducing the number of trips over the field and conserving fossil fuel energy and time of the farmer. Obviously required is a well advanced farming system and farmer for accommodating the technology required.

Foliar Fertilization

A published report of 1976 (23) gave evidence of striking response of soybeans to foliar application of the four major nutrients, NPKS, during the grain filling stage. Conjectured expectation for such response was the known atrophying of roots that occurs late in the growing season as photosynthates are being stored in the grain and are no longer supporting the root system with energy material for further extension and activity in nutrient uptake. If this were indeed conceptually correct the procedure should likewise be effective for all grain crops including wheat.

Several experiments were carried out in Nebraska and a large number of trials were conducted throughout the U.S. under the auspices of TVA during 1976-1978. A summation of those results was not promising for the procedure, there being essentially as many negative responses as positive with an average zero effect. In many cases a foliar burning was evident which undoubtedly explains all of the negative responses, and perhaps as well the other than promising overall results. It seems likely that a more favorable perspective might appear were it possible to make the foliar treatment when the surrounding environment is cool and humid rather than hot and dessicating, the latter being the usual situation during the mid and late summer in the U.S. The rice crop grown under submerged culture seemingly might be the most promising for consistent positive effects.

A two-year study of foliar fertilization of 30 wheat varieties included in the IWWPN during 1977 and 1978 at Yuma, Arizona, and Lincoln, Nebraska, provided the results presented in Tables 4, 5, and 6. There was an evident protein effect from the N component of the NPKS combination in two of the three experiments, but no treatment significantly affected grain yields in either year. The limited response at Yuma in 1977 and the lack of any response in protein to N in 1978 suggests a very high residual soil N supply or very liberal fertilization of the crop earlier in the crop year.

Fertilizer Impact On Grain Quality

The predominant effect of applied fertilizers on wheat quality is expressed in the protein content, and of all the known essential plant nutrients none has the impact on protein content of wheat to compare with that of N. Sulfur is much less commonly deficient in soils than N, but where it is seriously limiting, added N neither expresses itself fully in yield or protein level while various soluble non-protein forms may increase in both roots and tops (25). The metabolism of S and N seems to be closely related with one part readily available S being needed for each 12-16 of available N for maximum yield and protein production (25, 26).

Table 4. Grain yield (bu/A) and protein content (%) of winter wheat in response to foliar applied fertilizer treatments (Yuma, Arizona, 1977)

Variety (30 entries)	Foliar Applied Fertilizer Treatment										Variety Averages	
	N + P + K + S (complete)		N + P + K (-S)		N + P + S (-K)		N + K + S (-P)		P + K + S (-N)			
	Y	P	Y	P	Y	P	Y	P	Y	P	Y	P
Priboy	81.8	(12.8)	85.3	(13.0)	98.7	(12.6)	86.1	(12.8)	88.9	(12.6)	88.1	(12.8)
Tam 102	86.5	(13.0)	83.6	(12.3)	80.9	(12.8)	77.0	(13.2)	90.9	(12.6)	83.8	(12.8)
NE68719	83.3	(13.4)	83.8	(13.5)	79.1	(13.5)	86.2	(13.4)	83.1	(13.3)	83.1	(13.4)
Sadovo-1	88.4	(13.3)	77.4	(13.2)	77.7	(13.8)	76.4	(13.9)	86.6	(13.2)	81.3	(13.5)
CI13449/Ctk	85.1	(13.0)	75.9	(13.2)	79.1	(13.1)	78.5	(12.9)	81.6	(12.5)	80.0	(13.0)
Blueboy II	81.6	(12.6)	77.9	(12.5)	77.9	(12.4)	78.6	(12.5)	81.3	(12.3)	79.5	(12.5)
Zlatna Dolina	80.0	(12.9)	69.8	(14.2)	75.9	(13.5)	85.2	(14.2)	78.6	(12.8)	77.9	(13.5)
Lindon	75.5	(13.4)	78.7	(13.3)	75.0	(13.3)	71.4	(13.5)	75.3	(12.7)	75.2	(13.2)
Timwin	68.7	(13.0)	78.2	(12.5)	73.7	(13.2)	69.6	(13.3)	78.5	(12.6)	73.8	(12.9)
Sava	69.3	(14.0)	71.3	(14.1)	80.2	(14.0)	72.9	(14.3)	69.3	(13.8)	72.6	(14.0)
Zenith	70.1	(13.4)	74.1	(13.9)	75.7	(14.4)	64.7	(13.5)	77.2	(12.7)	72.3	(13.6)
Dacia	70.6	(14.7)	69.9	(14.2)	70.5	(14.5)	71.1	(14.6)	72.6	(14.3)	71.0	(14.5)
Centurk	65.7	(14.2)	64.3	(14.3)	70.9	(14.0)	68.2	(13.9)	75.9	(13.4)	69.0	(14.0)
Sage	70.9	(13.7)	68.4	(13.6)	67.2	(14.0)	64.4	(13.4)	72.8	(13.6)	68.7	(13.7)
Talent	70.0	(13.7)	71.0	(14.0)	66.3	(13.9)	70.8	(13.9)	61.4	(13.6)	67.9	(13.8)
WA5829	63.2	(11.9)	61.1	(12.2)	66.7	(12.1)	75.1	(11.7)	69.7	(11.3)	67.1	(11.8)
Bezostaya 1	64.7	(14.1)	66.4	(14.0)	65.8	(14.1)	66.1	(14.1)	66.8	(13.7)	65.9	(14.0)
Odesskaya 51	66.2	(14.0)	66.7	(13.9)	64.7	(14.2)	65.1	(14.2)	64.7	(14.2)	65.5	(14.1)
MV-3	67.5	(15.2)	66.8	(14.8)	69.5	(14.8)	58.3	(14.6)	61.5	(14.7)	64.7	(14.8)
F26-70	61.0	(15.7)	61.9	(15.8)	63.9	(15.9)	61.9	(16.2)	65.0	(15.3)	62.7	(15.8)
Favorit	59.7	(15.3)	60.3	(15.0)	61.2	(15.0)	63.4	(15.3)	61.3	(14.9)	61.2	(15.1)
Lancota	61.3	(14.6)	59.8	(14.6)	55.1	(15.0)	66.8	(14.7)	57.3	(14.4)	60.1	(14.7)
NE73640	52.2	(14.4)	62.2	(13.8)	61.6	(14.2)	62.3	(14.2)	57.7	(13.8)	59.2	(14.1)
WWP7147	50.7	(13.8)	56.5	(14.1)	59.8	(13.7)	56.3	(13.6)	56.2	(13.1)	55.9	(13.7)
Lely	60.1	(15.1)	53.7	(15.7)	55.4	(14.8)	48.2	(15.9)	52.5	(14.0)	54.0	(15.1)
Maris Huntsman	51.5	(14.3)	50.5	(13.0)	47.4	(13.3)	52.5	(13.2)	53.6	(12.8)	51.1	(13.3)
Oasis	48.8	(14.7)	52.6	(13.9)	53.8	(14.4)	46.5	(13.6)	49.0	(14.4)	50.1	(14.2)
Mironovskaya 808	50.8	(14.4)	51.5	(13.9)	44.8	(14.1)	49.0	(14.9)	51.1	(13.7)	49.4	(14.2)
Probstdorfer Extrem	42.0	(15.1)	43.7	(14.9)	39.2	(15.5)	45.6	(15.1)	42.6	(14.5)	42.6	(15.0)
Kormoran	44.4	(15.5)	36.4	(15.4)	39.7	(15.5)	40.1	(15.3)	39.2	(15.1)	40.0	(15.3)
Foliar fert. ave.	66.4	(14.0)	66.0	(13.9)	66.7	(14.0)	65.9	(14.0)	67.4	(13.5)		

F-TEST FOR YIELD NS: PROTEIN $LSD_{05} = 0.15$

VARIETY X FOLIAR FERTILIZER F-TEST NS FOR YIELD AND PROTEIN

Table 5. Grain yield (bu/A) and protein content (%) of winter wheat in response to foliar applied fertilizer treatments (Lincoln, Nebraska, 1977)

Variety (23 entries)	Foliar Applied Fertilizer Treatments, Lincoln, 1977										Variety Averages (Descending order)	
	N + P + K + S (complete)		N + P + K (-S)		N + P + S (-K)		N + K + S (-P)		P + K + S (-N)			
	Y	P	Y	P	Y	P	Y	P	Y	P	Y	P
NE68719	47.8	(15.1)	48.4	(14.4)	51.4	(15.5)	52.6	(15.6)	52.3	(14.2)	50.5	(14.8)
Sage	46.9	(15.5)	46.0	(15.1)	49.1	(15.2)	45.6	(15.3)	61.8	(14.4)	49.9	(15.1)
Centurk	52.6	(14.5)	48.0	(14.4)	50.2	(14.2)	42.5	(14.6)	45.9	(13.8)	48.0	(14.3)
Odesskaya 51	46.8	(14.7)	48.6	(14.5)	48.2	(14.8)	47.8	(14.8)	46.5	(14.3)	47.6	(14.6)
Lancota	45.0	(15.9)	47.6	(16.0)	42.3	(16.0)	48.6	(16.1)	47.1	(15.7)	46.1	(15.9)
Lindon	43.8	(14.3)	47.0	(14.2)	47.7	(14.1)	44.0	(14.3)	44.3	(13.9)	45.4	(14.1)
Tam 102	36.7	(15.1)	40.8	(15.3)	46.0	(14.6)	54.2	(14.2)	45.6	(14.0)	44.7	(14.6)
MV-3	48.8	(15.2)	42.2	(15.9)	45.3	(15.6)	44.6	(15.9)	35.6	(14.9)	43.3	(15.5)
NE73640	46.3	(15.1)	40.0	(16.6)	41.2	(15.3)	40.4	(15.7)	44.7	(15.6)	42.5	(15.7)
CI13449/Ctk	38.2	(14.5)	42.6	(14.5)	42.6	(14.7)	40.3	(15.1)	46.9	(13.8)	42.1	(14.5)
Bezostaya 1	41.8	(15.4)	37.9	(15.7)	39.7	(15.4)	45.8	(15.1)	42.1	(15.0)	41.5	(15.3)
WWP7147	38.5	(16.0)	39.9	(16.2)	39.0	(16.3)	42.3	(16.6)	43.0	(15.4)	40.5	(16.1)
Timwin	34.0	(14.5)	30.6	(15.4)	44.8	(15.7)	41.2	(15.5)	36.7	(15.3)	37.5	(15.3)
Probstdorfer Extrem	37.9	(17.5)	34.7	(17.7)	33.1	(17.9)	37.9	(18.6)	40.2	(16.7)	36.8	(17.7)
Dacia	39.6	(18.3)	35.4	(17.9)	36.4	(18.1)	35.5	(17.9)	34.6	(17.2)	36.3	(17.9)
Favorit	32.5	(17.7)	35.1	(17.4)	37.9	(17.8)	29.6	(17.5)	38.5	(16.9)	34.7	(17.5)
Mironovskaya 808	28.5	(17.7)	28.2	(17.1)	31.9	(17.2)	26.9	(16.4)	37.4	(16.3)	30.9	(16.9)
Blueboy II	28.0	(15.8)	30.6	(15.3)	27.3	(15.4)	35.2	(15.4)	30.1	(14.4)	30.2	(15.3)
F26-70	28.9	(17.0)	29.8	(16.7)	30.8	(16.9)	27.4	(16.5)	29.6	(16.2)	29.3	(16.7)
WA5829	31.7	(14.7)	23.6	(15.1)	28.0	(15.1)	33.3	(15.1)	28.4	(14.4)	29.0	(14.9)
Pribcy	25.0	(15.8)	28.0	(15.9)	30.9	(15.8)	21.2	(16.4)	29.0	(15.1)	27.4	(15.8)
Zenith	16.3	(18.4)	16.7	(18.6)	17.0	(20.0)	19.3	(20.3)	20.0	(17.8)	17.8	(19.0)
Kormoran	17.4	(18.0)	21.7	(16.7)	19.3	(18.0)	14.5	(18.6)	16.0	(16.8)	17.8	(17.6)
Foliar fert. ave.	37.1	(15.9)	36.7	(15.9)	38.3	(16.1)	38.0	(16.1)	39.0	(15.3)		

F-TEST FOR YIELD NS; PROTEIN $LSD_{05} = 0.2$

VARIETY X FOLIAR FERTILIZ ER F-TEST NS FOR YIELD AND PROTEIN

Table 6. Grain yield (bu/A) and protein content (%) of winter wheat in response to foliar applied fertilizer treatments (Yuma, Arizona, 1978).

Variety (30 entries)	Foliar Applied Fertilizer Treatment													
	N + P + K + S (complete)		N + P + K (-S)		N + P + S (-K)		N + K + S (-P)		P + K + S (-N)		Control (0)		Variety Averages	
	Y	P	Y	P	Y	P	Y	P	Y	P	Y	P	Y	P
Newton-KS73112	68.6	(14.5)	59.0	(15.2)	56.8	(14.8)	62.1	(15.3)	63.7	(14.8)	70.7	(14.6)	63.5	(14.9)
Budifen	57.3	(12.6)	49.2	(12.5)	57.3	(12.6)	69.8	(13.0)	62.5	(12.6)	61.7	(12.9)	59.6	(12.7)
Samson	59.1	(15.4)	52.9	(14.9)	69.5	(15.2)	55.0	(15.4)	62.2	(15.4)	41.6	(15.7)	57.0	(15.3)
3006-44	56.7	(15.3)	52.8	(15.9)	50.7	(15.4)	56.8	(15.2)	52.3	(15.1)	48.3	(15.8)	52.0	(15.5)
Tam102	49.8	(15.6)	45.2	(15.4)	43.4	(15.5)	37.4	(15.7)	55.4	(15.9)	50.0	(15.1)	46.8	(15.5)
NE68719	48.6	(16.1)	58.7	(15.6)	44.1	(16.0)	45.3	(15.4)	35.4	(15.6)	44.2	(16.2)	46.1	(15.8)
Sadovo-1	42.2	(16.7)	51.6	(16.0)	49.6	(16.2)	44.8	(16.9)	44.1	(16.2)	43.7	(17.2)	46.0	(16.5)
Lindon	43.5	(16.2)	48.2	(16.3)	47.7	(16.3)	42.7	(16.5)	47.7	(15.7)	44.7	(15.9)	45.7	(16.2)
GK-Protein	47.9	(18.6)	41.0	(18.3)	42.7	(18.3)	47.7	(18.4)	45.0	(18.2)	43.9	(18.1)	45.0	(18.3)
Zenith	45.5	(17.7)	46.5	(17.3)	44.0	(17.6)	42.0	(17.0)	39.7	(17.1)	38.7	(17.5)	42.8	(17.4)
Priboy	42.1	(14.6)	43.5	(14.5)	45.7	(14.4)	40.4	(14.5)	41.5	(14.9)	42.6	(14.8)	42.6	(14.6)
Timwin	40.0	(16.8)	36.0	(16.9)	44.5	(16.5)	45.3	(16.8)	46.8	(16.8)	42.9	(17.1)	42.6	(16.8)
Zlatna Dolina	39.1	(16.7)	41.2	(16.5)	37.4	(16.8)	41.9	(16.6)	46.1	(16.7)	44.0	(16.6)	41.6	(16.7)
Blueboy II	46.8	(15.0)	42.1	(15.1)	40.9	(15.5)	37.9	(14.8)	42.0	(14.9)	39.3	(15.5)	41.5	(15.1)
Sava	38.1	(16.9)	39.6	(16.3)	42.7	(16.1)	40.7	(16.4)	34.1	(16.7)	45.0	(15.7)	40.0	(16.4)
CI13449/Ctk	41.4	(14.9)	36.9	(15.4)	40.2	(14.8)	40.4	(15.3)	40.6	(14.9)	40.3	(14.8)	40.0	(15.0)
Dacia	46.1	(17.4)	41.9	(17.5)	34.0	(18.6)	32.8	(18.0)	42.0	(18.2)	38.8	(17.6)	39.3	(17.9)
F26-70	39.1	(18.7)	36.8	(18.6)	36.7	(18.4)	40.0	(18.2)	36.7	(18.1)	38.4	(18.5)	38.0	(18.4)
MV-3	36.2	(17.8)	34.5	(18.2)	38.2	(17.9)	32.0	(17.9)	51.2	(18.5)	34.8	(17.8)	37.8	(18.0)
Talent	37.1	(16.3)	40.2	(16.2)	43.0	(16.3)	33.6	(16.4)	33.9	(16.4)	36.8	(16.0)	37.4	(16.3)
Bezostaya 1	39.4	(17.4)	38.4	(17.3)	28.5	(17.8)	38.3	(17.2)	36.5	(16.9)	34.1	(17.5)	35.9	(17.4)
NE7060	34.8	(17.9)	38.6	(17.9)	30.5	(18.3)	35.9	(17.6)	34.1	(18.0)	40.4	(17.4)	35.7	(17.9)
Favorit	33.8	(18.4)	31.5	(18.2)	35.2	(18.0)	37.7	(18.0)	34.8	(17.9)	36.6	(18.4)	34.9	(18.1)
Odesskaya 51	32.8	(16.8)	30.3	(16.8)	29.8	(16.5)	33.0	(16.9)	33.0	(16.8)	30.6	(16.2)	31.6	(16.7)
Maris Huntsman	31.7	(16.9)	33.4	(16.8)	29.2	(16.6)	30.9	(17.2)	27.7	(16.6)	28.9	(17.6)	30.3	(16.9)
WWP7147	33.0	(17.8)	30.8	(16.8)	23.3	(19.0)	30.3	(17.6)	29.2	(17.7)	32.6	(17.5)	29.9	(17.7)
Nap Hal/Atlas 66	31.2	(19.7)	27.8	(19.7)	27.9	(20.1)	26.7	(19.7)	29.4	(20.1)	30.3	(20.5)	28.8	(19.9)
NE73640	27.3	(16.9)	30.9	(17.0)	25.3	(16.0)	31.5	(16.1)	25.3	(17.0)	23.3	(16.9)	27.3	(16.7)
WA5829	23.7	(15.2)	29.2	(15.3)	26.3	(15.7)	27.4	(15.5)	27.5	(15.8)	26.3	(14.8)	26.7	(15.4)
Kormoran	26.2	(18.3)	16.5	(17.6)	15.9	(17.8)	17.6	(18.9)	18.2	(18.4)	16.8	(18.2)	18.5	(18.2)
Foliar fert. ave.	41.3	(16.6)	40.2	(16.5)	39.4	(16.6)	39.9	(16.6)	40.6	(16.6)	39.7	(16.6)	40.2	(16.6)

F-TEST NS

VARIETY X FOLIAR FERTILIZER F-TESTS NS

Rate of N Fertilizer. When water and other factors are favorable, the effect of the first applied N increment to a N deficient crop is to increase total yield with negative effects on protein content. Above that minimal rate that increases yield at the expense of protein the rate of protein increase from thence onward is usually a near straight line function with rate of N until some protein maximum for the varieties employed is reached, normally well in excess of the rate required for maximum grain yield.

All varieties do not perform the same in N rate studies. Johnson et al. (8) showed positive responses in protein of two wheat varieties to increasing rate of applied N. An experimental variety, CI 14016, maintained a consistent two percent protein advantage over Lancer at all N rates. Lancer reached its peak in yield at 12 percent protein with 90 kg N/ha, whereas the experimental was still on the incline portion of the yield curve at 135 kg N/ha and 16.3 percent protein. In addition, the protein yield curve for the experimental variety continued as a straight line function throughout the N rates employed.

As noted earlier a common hazard of a high level of fertility on cereals in the drier regions is overstimulation, the effect of N being most apparent because of its greater stimulative effect on vegetative growth than that caused by other nutrients. Excessive vegetative growth uses available soil moisture at the expense of grain yield. However, reduced grain yield due to lack of available soil moisture usually results in higher than normal protein percentage. This is often found to occur in the wheat growing areas of the High Plains. While these observations are valid for protein percentage, maximum protein production commonly occurs when high yields are achieved.

It is apparent that the amount of fertilizer N required to maximize grain yields is not adequate to produce maximum protein. Therefore, the relation between N cost and the value of increased protein content determines the rate of N that a producer ultimately uses. Without reimbursement for producing a high protein product, producers will apply N to provide optimum grain yields only.

Time of N fertilizer application. Protein percentage tends to become progressively higher as time of N application is delayed, providing precipitation is received to carry the N to the root system. With foliar treatments N application may be delayed so that the entire expressed N effect is on protein and not at all on yield (4). Isotopic tracer studies have demonstrated, for example, that N taken into the wheat plant after the boot stage does not equilibrate with N already present in the plant and is rather more directly channeled into the grain (7).

Most studies on winter wheat indicate that applying N in the spring results in a higher grain protein content than results from fall application with a slight yield advantage in the semi-arid wheat producing areas (6, 15). It appears that the latest possible application of N commensurate with crop stage of development and growing conditions that permit ready N uptake provide for maximum protein yields. This result seems to derive in part from the N so applied being available in quantity throughout the period of grain formation and not having been partially consumed for the production of unnecessary vegetative growth. A contributing factor with many soils and environmental conditions is the reduced opportunity for losses to leaching, runoff, volatilization and/or denitrification with late application because of the active root system already present in the soil for absorbing the N when it is applied.

Significance of Residual Soil N. A most significant factor influencing grain and protein yield response to applied fertilizer N is the amount of residual mineral N remaining in the rooting profile at the beginning of the crop season. Nebraska experience indicates that with sites high in residual nitrate, non-responsive in yield, the principal effect of applied N was an increase in protein content. Where residual nitrate was low in the 180-cm profile, on the other hand, the predominant effect of applied N was to increase yield with slight effects on protein within the range of N rates studied (16). A site with low residual nitrate receiving any reasonable rate of N will not afford equivalent protein to that of the site with high residual N. This has been explained on the basis of a declining root activity with moisture depletion from the surface downward through the growing season restricting utilization of fertilizer N placed in the surface layer. Some reasonable quantity of available N must be present in lower soil horizons where root activity is greatest during the protein-setting stage of grain formation for high protein to result, alternatively accomplished by late foliar feeding.

Because of the mobility of the nitrate ion, residual NO_3^--N can be expected to have greatest significance in the drier climatic regions, although its importance has been recognized even in the humid tropics. The significance of this residual has been documented for grain and protein yields of winter wheat grown in the semi-arid to sub-humid climatic environment of Nebraska (16).

Availability of N in itself, whether residual or applied or both, is not adequate for explaining observed variability in protein content of cereals from one site to another. Recent studies indicate, however, that highly predictable results are possible when a number of measurable parameters are taken into account. Thus, in a Colorado-Nebraska study with wheat where the four factors of residual NO_3^--N in the 1.5 m soil profile at planting, precipitation during a 15-day period 40-55 days before maturity, available water to 1.5 m depth at seeding, and

maximum air temperature for a 5-day period 15-20 days before maturity were combined in multiple correlation with protein content, 96 percent of the variation in protein could be explained (24).

References Cited

1. Dreier, A.F., D. Heuermann, and R.A. Olson. 1967. Fertilizers--what kind do you use? Nebr. Agr. Exp. Sta. Quart. 11: 25-28.

2. Dreier, A.F., R.A. Olson, A.D. Flowerday, P.H. Grabouski, L.A. Daigger and E.G. Schwartz. 1966. Small grain fertilizer experiments in Nebraska. O.S.T. Circ. 125:42pp.

3. Duley, F.L. 1930. Methods of applying fertilizers to wheat. Jour. Amer. Soc. Agron. 22:515-521.

4. Finney, K. F., J.W. Meyer, F.W. Smith and H.C. Fryer. 1957. Effect of foliar spraying of Pawnee wheat with urea solutions on yield, protein content and protein quality. Agron. J. 49: 341-347.

5. Foy, C.D., G.R. Burns, J.C. Brown, and A.L. Fleming. 1965. Differential aluminum tolerance of two wheat varieties associated with plant induced changes around their roots. Soil Sci. Soc. Amer. Proc. 29:65-67

6. Hucklesby, D.P., G.M. Brown, S.E. Howell, and R.H. Hageman. 1971. Late spring applications of N for efficient utilization and enhanced production of grain protein of wheat. Agron. J. 63:274-276.

7. IAEA. 1975. Isotope studies on wheat fertilization. Tech. Rept. Ser. 157: 99pp. IAEA, Vienna, Austria.

8. Johnson, V.A., A.F. Dreier, and P.H. Grabouski. 1973. Yield and protein responses to nitrogen fertilizer of two winter wheat varieties differing in inherent protein content of their grain. Agron. J. 65:259-263.

9. Karathanasis, A.D., V.A. Johnson, G.A. Peterson, D.H. Sander, and R.A. Olson. 1980. Relation of soil properties to grain yield and quality of winter wheat grown at international sites. Agron. J. 72:229-336.

10. Lopes, A.S. 1975. A survey of the fertility status of soils under "Cerrada" vegetation in Brazil. M.S. thesis. North Carolina State University, Raleigh, N.C.

11. Malhi, S.S., and M. Nyberg. 1978. The fate of fall-applied nitrogen in northern Alberta as determined by the ^{15}N technique. 11th Internat. Cong. of Soil Sci. 1:370.

12. Miller, M.H., and A.J. Ohlrogge. 1958. Principles of nutrient uptake from fertilizer bands. I. Effect of placement of N fertilizer on the uptake of band-place P at different soil P levels. Agron. J. 50:95-97.

13. LeiKam, D. F., R. E. Lamond, P. J. Gallagher, B. Hall, K. W. Kelley, D. D. Scott, W. A. Moore, and L. S. Murphy. 1977. Comparisons of methods of N and P application for wheat. Report of Progress, 313:20-22. Kansas Agr. Exp. Sta.

14. Olson, R. A., and A. F. Dreier. 1956. Nitrogen a key factor in fertilizer phosphorus efficiency. Soil Sci. Soc. Amer. Proc. 20:509-514.

15. Olson, R. A., A. F. Dreier, C. Thompson, K. Frank, and P. H. Grabouski. 1964. Using fertilizer nitrogen effectively on grain crops. Sta. Bull. 479:42 pp. Nebr. Agr. Exp. Sta.

16. Olson, R. A., K. D. Frank, A. F. Dreier, D. H. Sander, and V. A. Johnson. 1976. Impact of residual mineral N in soil on grain protein yields of winter wheat and corn. Agron. J. 68:769-772.

17. Olson, R. A., and H. F. Rhoades. 1953. Commercial fertilizers for winter wheat in relation to the properties of Nebraska soils. Nebr. Agr. Exp. Sta. Res. Bull. 172:84 pp.

18. Olson, R. A., D. H. Sander, and A. F. Dreier. 1972. Soil Analyses -- are they needed for nursery data interpretation? In V. A. Johnson (Ed) 1st International Winter Wheat Conf. Proc.:179-192. USDA, USAID, and Nebr. Agr. Exp. Sta., Ankara, Turkey.

19. Olson, R. A., C. A. Thompson, P. H. Grabouski, D. D. Stuckenholtz, K. D. Frank, and A. F. Dreier. 1964. Water requirement of grain crops as modified by fertilizer use. Agron. J. 56:427-432.

20. Peterson, G. A., D. H. Sander, and L. Daigger. 1974. Soil series -- a key to nitrogen fertilization of wheat. Nebr. Farm, Home & Ranch Quart. 20:12-14.

21. Peterson, G. A., D. H. Sander, P. H. Grabouski, and M. L. Hooker. 1980. A new look at row and broadcast phosphate recommendations for winter wheat. Agron. J. 72: in press.

22. Ramig, Robert E., and H. F. Rhoades. 1963. Interrelationships of soil moisture level at planting time and nitrogen fertilization on winter wheat production. Agron. J. 55:123-127.

23. Ramon, Garcia L., and J. J. Hanway. 1976. Foliar fertilization of soybeans during the seed-filling period. Agron. J. 68:653-657.

24. Smika, D. E., and B. W. Greb. 1973. Protein content of winter wheat grain as related to soil and climatic factors in the semi-arid central Great Plains. Agron. J. 65:433-436.

25. Stewart, B. A., and L. K. Porter. 1969. Nitrogen-sulfur relationship in wheat, corn and beans. Agron. J. 61:267-271.

26. Terman, G.L., S.E. Allen, and P.M. Giordano. 1973. Dry matter yield - N and S concentration relationships and ratios in young corn plants. Agron. J. 65:633-636.

27. Viets, Frank G., Jr. 1962. Fertilizers and the efficient use of water. Adv. in Agronomy 14:223-264.

28. Waldren, R.P. and A.D. Flowerday. 1979. Growth stages and distribution of dry matter, N, P, and K in winter wheat. Agron. J. 391-397.

29. Wright, B.C. 1972. Fertilization of fall-planted spring wheat under irrigation. In V.A. Johnson (Ed) 1st Internat. Winter Wheat Conf. Proc.: 59-62. USDA, USAID, and Nebr. Agr. Exp. Sta., Ankara, Turkey.

SOIL MANAGEMENT FOR RAINFED WHEAT PRODUCTION

C. R. Fenster
United States

Abstract

Much of the wheat production in the world occurs in semi-arid regions (less than 50 cm of precipitation per year). Traditional cultural practices to control weeds have relied on repeated tillage operations. Further, in many areas, heavy grazing occurs during the fallow period. This along with repeated tillage operations leave the soil bare and subject to wind and water erosion and high evaporation. To increase the effectiveness of precipitation in the semi-arid regions for crop production, considerations must be given to: 1) cropping systems to take advantage of seasonal precipitation; 2) cultural practices between crops which permit the accumulation of moisture in the soil profile; 3) weed control to eliminate competition with the crop for moisture and nutrients; 4) management of the soil surface for water intake and moisture storage in the soil profile; and, 5) proper methods and date-of-planting of the crop. The potential yield of wheat is much higher in the semi-arid regions of the world than is being achieved currently with present production practices. Cropping systems need to be developed that produce grain and forage, specifically. Weeds and crop residues nutritionally are poor forage for animals. Emphasis needs to be given to technological practices that will conserve and utilize more of the precipitation that falls on the land for crop production.

Introduction

Semi-arid regions (defined as receiving an average of less than 50 cm of rainfall per year) comprise more than 50 percent of the earth's surface. Much of the wheat that is grown in these regions is limited to only rainfall moisture which may be erratic in amount and frequency. High intensity winds are also a feature with which to contend. During wet periods, high intensity rains may cause erosion followed by periods of low rainfall and serious wind erosion. Precipitation in some areas is primarily winter rainfall followed by hot, dry summers. In areas with cold winters, the precipitation generally occurs in early spring and summer during the growing season.

Traditional cultural practices for wheat have relied on repeated tillage operations to control weeds. In many areas of the world, the weed growth and crop residues are heavily grazed. Tillage, especially when grazing is practiced, leaves the soil bare and subject to wind and water erosion and high moisture evaporation. Each time a tillage operation is performed, moist soil is exposed to the air resulting in moisture loss.

University of Nebraska Panhandle Station, Scottsbluff

The potential yield of wheat is much higher in the semi-arid regions than is being realized with present production practices. Technological methods have been and are being developed that conserve more of the precipitation that falls on the land for utilization in increasing wheat yields. Emphasis must be placed on water-use efficiency. To increase the effectiveness of precipitation for crop production, consideration must be given to: 1) cropping systems that take advantage of the growing season precipitation; 2) cultural practices during the period between crops which permit the accumulation of moisture in the soil profile; 3) weed control as weeds are heavy users of soil nutrients and water in competition with the crop; 4) surface condition of soil to permit maximum intake and storage of water in the soil profile; and, 5) proper method and date-of-planting of the crop.

Winter wheat yields have steadily increased in western Nebraska since 1940 (Figure 1). Increases can be largely attributed to development and implementation of technological practices for the total production system. Following is an estimate of the percent increase in yield of winter wheat due to new and improved technology.

Improved varieties 30%

- Genetical higher yield factor.
- Disease resistance.
- Insect resistance.
- Shorter straw.

Improved storage of soil water 35%

- Improved tillage techniques for optimum water infiltration.
- Better weed control from harvest to planting of the wheat. Also, weed control in the growing wheat.
- Maintenance of crop residues.
- Runoff and erosion control.

Improved planting techniques 20%

- Proper rate, dates and methods of planting.

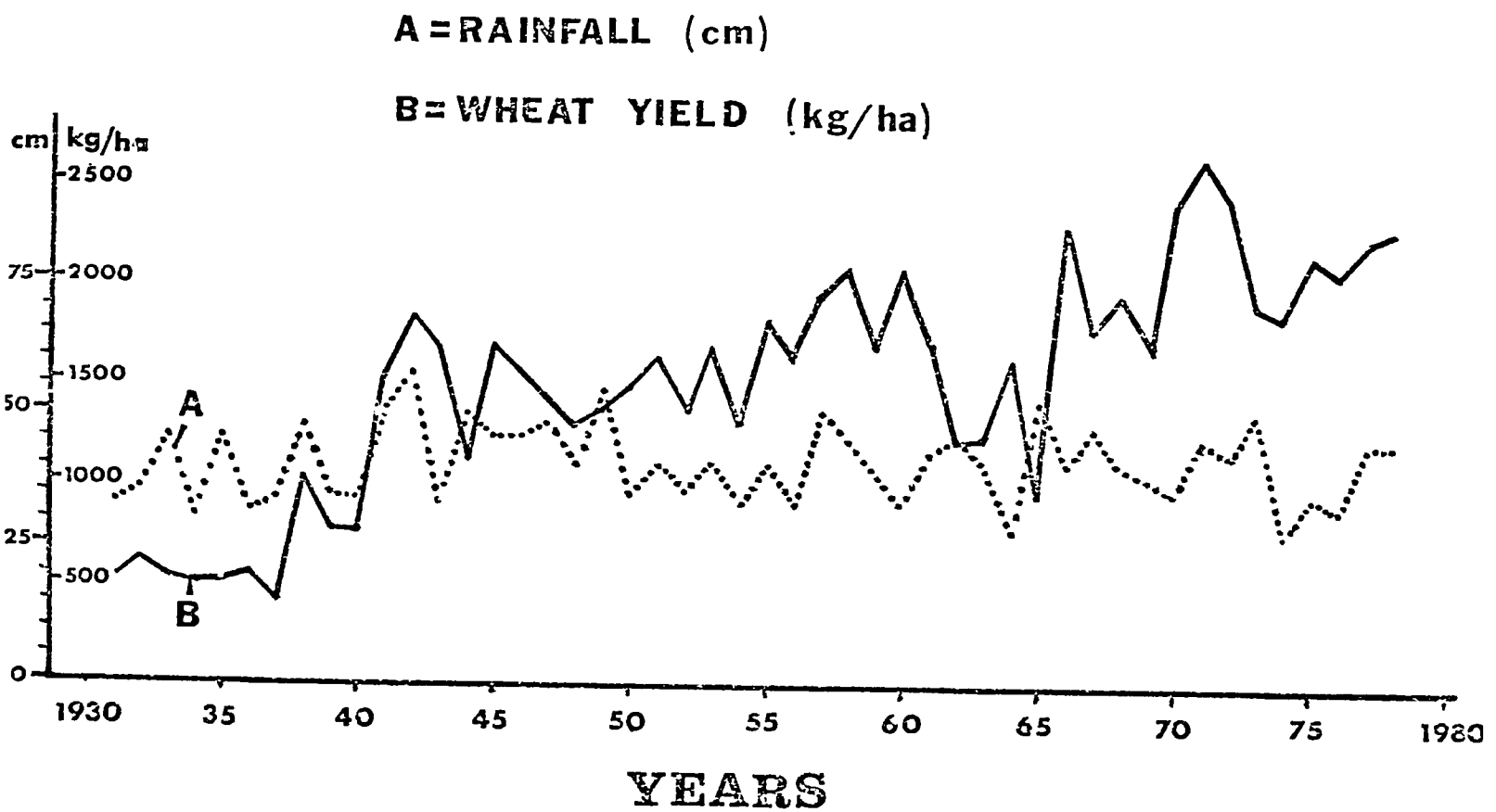
Improved harvesting techniques 10%

- More timely and efficient.
- Less handling of grain.

Fertilizer, especially on sand and low fertility soils 5%

Fig. 1

NEBRASKA PANHANDLE AVERAGES



Cropping Systems That Take Advantage of the Seasonal Precipitation

To determine which crops to grow, seasonal precipitation and climatic conditions must be considered. Figures 2 and 3 show the normal precipitation pattern in the central Great Plains of the USA. Based on that pattern, the following facts need to be considered in relation to crop production: 1) precipitation is low (mostly snow) with the soil frozen and winter wheat dormant throughout December, January and February; 2) high temperatures in July and August preclude significant moisture storage during this part of the summer fallow period; 3) however, any rain received on a summer crop such as corn or sorghum would reduce its demands on stored soil moisture; 4) precipitation is stored most efficiently in the spring and fall months; 5) stored soil moisture is usually exhausted as any crop matures; 6) winter wheat is well adapted to cold, dry winters with favorable precipitation during the spring months; 7) summer crops such as corn, sorghum and millet produce well during summers if soil moisture is sufficient and heat is not too excessive (Figure 2).

The control of weeds for 10 months after winter wheat harvest generally stores enough moisture for a summer crop such as corn, sorghum or millet which is usually planted in May. Summer rainfall supplements this moisture reserve and results in producing good yields for corn or sorghum which is harvested in October. Effective weed control through the next eleven months stores soil moisture ahead of winter wheat planting the following September. Spring rains supplement this stored moisture to provide an adequate amount to produce excellent winter wheat yields at harvest during early July before high summer temperatures can damage the crop.

If soil moisture is relatively low following the 10-month period after winter wheat harvest, the land can be fallowed for another 4 months and then planted to winter wheat. In areas where the normal rainfall is less than 40 cm per year and is primarily spring and summer rainfall, the winter wheat-fallow rotation is usually used exclusively (Figure 3).

Figure 4 shows a precipitation pattern from a semi-arid region with hot, dry summers of 4 to 6 months duration with the primary rainfall during the cool winter season. Under such a precipitation regime, spring varieties of barley and wheat when planted in the fall of the year can grow to maturity ahead of summer heat and drought. A multiple crop system as shown in Figures 2 and 3 would not fit this climatic pattern. Still the principle of weed control during the fallow period is extremely important for moisture storage of the fall rains so that the best date-of-planting and stand establishment can be more regularly achieved.

Fig. 2 Winter Wheat, Fallow, Sorghum, Fallow Rotation

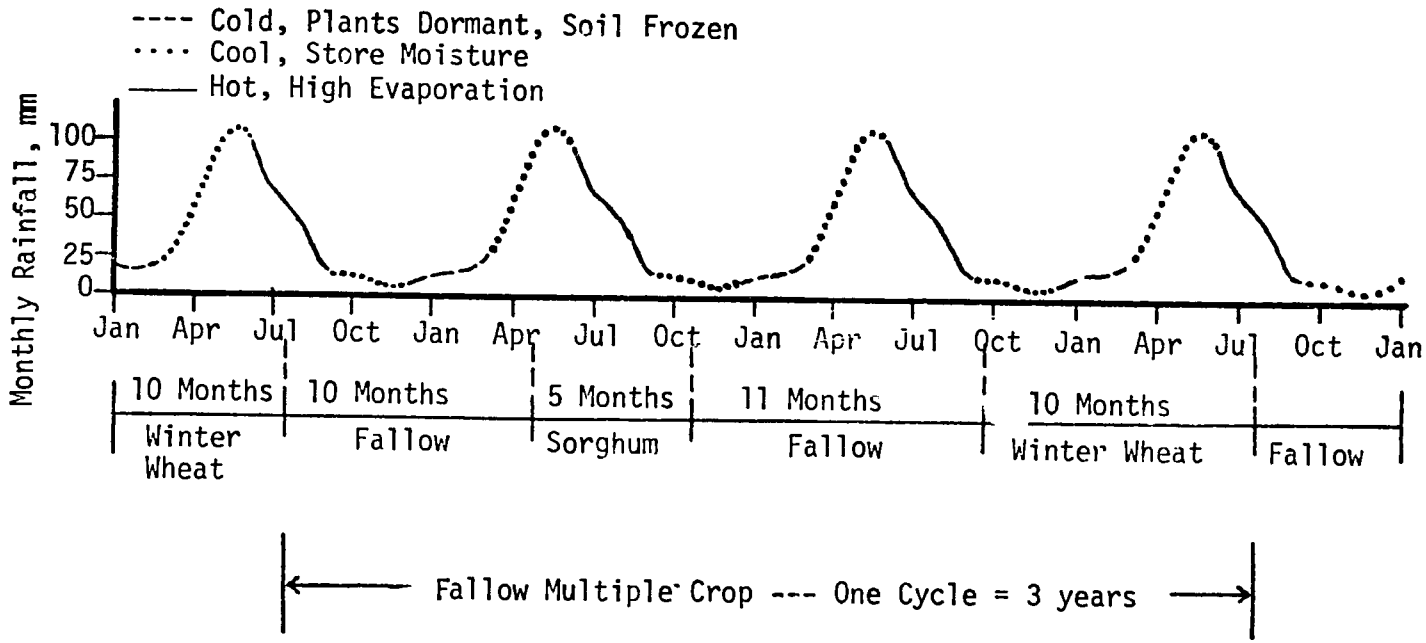


Fig. 3 Winter Wheat-Fallow Rotation

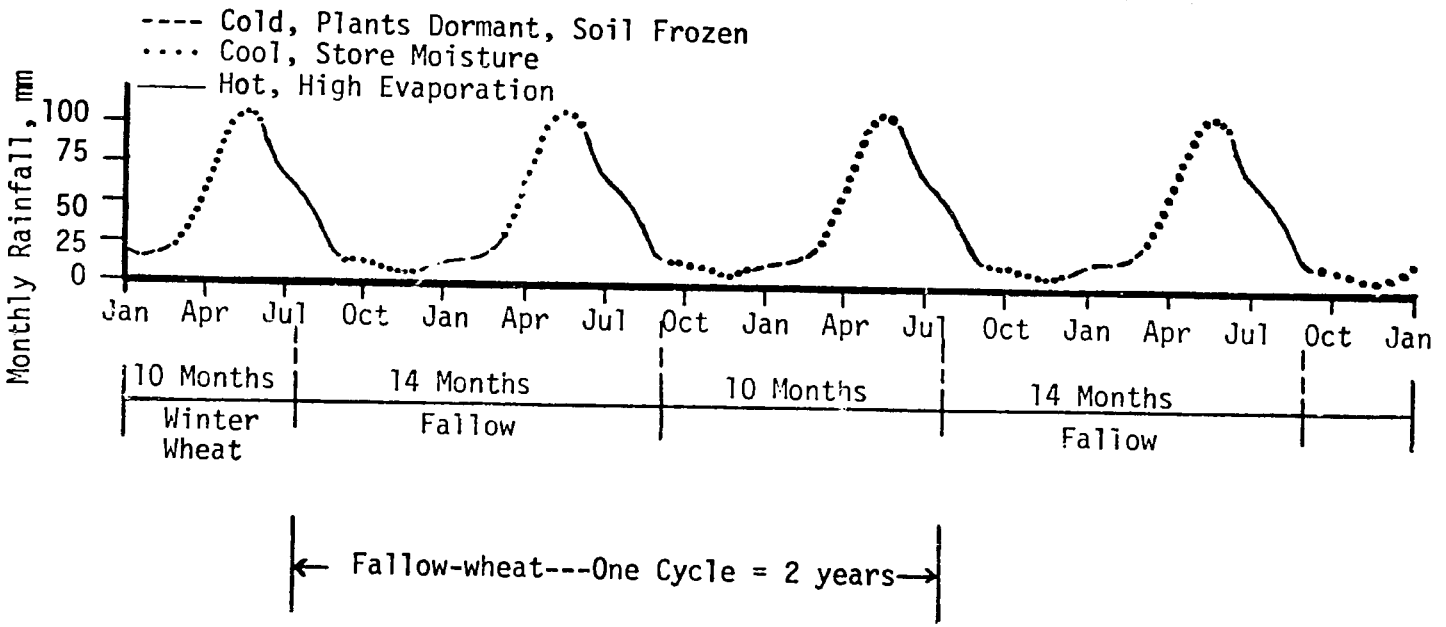
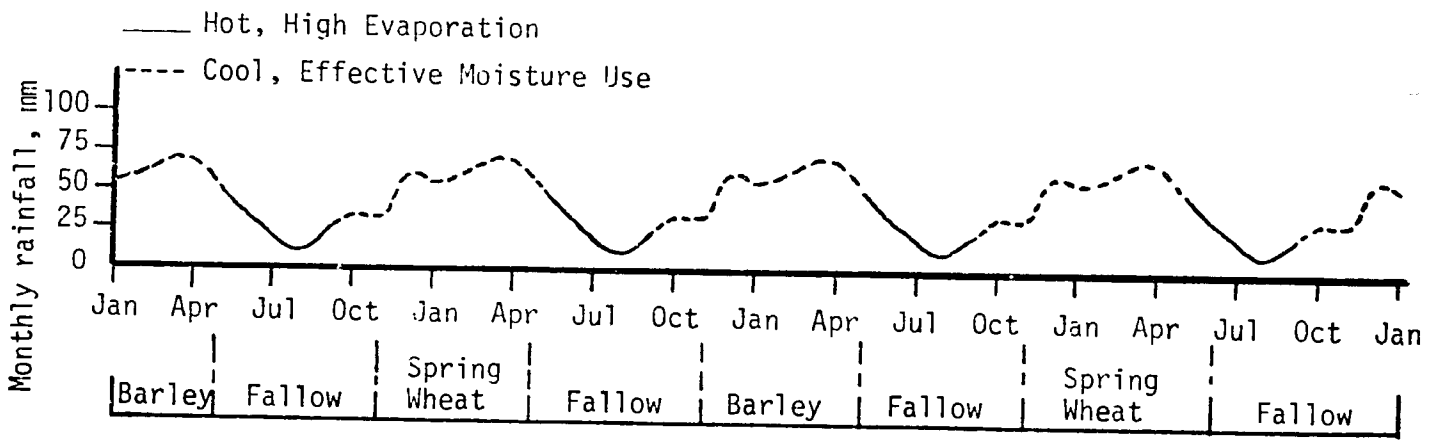


Fig. 4 Annual Cropping for Semi-Arid Region with Winter Rainfall but No Cold Season When Plants Are Dormant



Cultural Practices Between Crops Which Permit the Accumulation of Moisture in the Soil Profile

In the semi-arid areas (precipitation less than 50 cm), fallow may be used to accumulate sufficient moisture in the soil profile to give profitable crop production. "Fallow" is the period of time from the harvest of one crop to the planting of the next crop. An effective fallow program for moisture conservation requires that no crop is grown and all plant growth is controlled during the season by cultivation or herbicides. The fallow system became established about 1940 in the Great Plains and now approximately 16 million hectares of land in the Great Plains of the USA are fallowed in this manner each year.

In the Panhandle of Nebraska, which is part of the Great Plains, yields of winter wheat were relatively low prior to 1940 averaging about 660 kg/ha. Following the adoption of the fallow system, the yields of winter wheat more than doubled on an every-other-year basis and became secure from drought as indicated in Figure 1. Prior to 1950, most of the winter wheat land was fenced and pastured during the fallow period. Frequently, fields were shallow tilled after harvest to establish volunteer wheat for pasture. The volunteer wheat was pastured during the fall, winter and into the spring. Tillage for summer fallow would begin around June 1st to control weeds. By this time, the weeds including the volunteer wheat had taken most or all of the soil moisture from the soil profile.

In the middle of the 1960's, pasturing of fallow land was discontinued and more emphasis was placed on weed control and residue retention during the fallow period. The storage of more water in the soil profile along with improved varieties of winter wheat has tripled the yields of winter wheat in the fallow system during the late sixties and seventies. Yields of winter wheat will continue to increase with improved technology that improves water storage efficiency.

Data collected from different locations in the High Plains (Table 1) show more than twice the yields of winter wheat produced on fallow compared to continuous cropping except at Bushland, Texas, where the precipitation was 500 mm per year and the summers are very hot.

Fallowing in the Great Plains climate has increased the stability of agriculture by reducing the frequency of crop loss and improved total crop yield over the years. The fallow system when properly applied in a farming system in the Great Plains is favored because it effectively stores water for the subsequent crop, controls weeds, provides soil erosion control and accumulates available plant nutrients. Yields tend to be increased, production stabilized, labor better distributed and overall efficiency increased due to the fallowing.

Table 1. Comparison of yields from winter wheat-fallow and continuous winter wheat systems.*

Location	Annual precipitation mm	Wheat-fallow kg/ha	Continuous wheat kg/ha	No. of times increased
Akron, Colorado (60-yr. average)	437	1460	500	2.92
Colby, Kansas (49-yr. average)	455	1320	620	2.13
North Platte, Nebraska (56-yr. average)	445	2090	830	2.52
Alliance, Nebraska (23-yr. average)	414	1230	500	2.46
Bushland, Texas (29-yr. average)	500	1010	650	1.55

* Adapted from ARS-USDA Conservation Research Report No. 17, 1974.

Weed Control

Weeds are the major economic pest of wheat (Irving and LeClerg, 1965; and Nalewaja, 1972). Yield losses to weeds depend upon the weed species, density, time and amount of weed growth. Wheat cultivar selection and management, climatic conditions and edaphic factors also influence weed growth and the resulting effects. Because of weed competition for moisture, nutrients and light, there is an inverse relationship between weed growth and wheat yields. At Alliance and North Platte, Nebraska, Wicks and Fenster (unpublished) showed that a moderate infestation of downy brome (9 to 10 plants per square meter) reduced winter wheat yields 30 percent and a heavy infestation 80 percent.

Weeds compete early in the life cycle of wheat and continue to compete as long as they are allowed to grow. Winter wheat starts growth in the fall and, unless stand reduction occurs due to winterkill, vigorous plant growth will utilize the soil surface moisture and produce sufficient foliage to densely shade the soil before summer annual weeds can become established. Winter annual weeds germinate at the same time as or later than winter wheat and are able to grow unchecked.

Weeds infesting spring wheat primarily are early maturing summer annuals while winter wheat is infested by winter annual weeds or broadleaf weeds that germinate in early spring. Perennial

weed problems tend to increase as tillage decreases. Grassy weeds are a greater problem than broadleaf weeds since control methods which use reasonably priced herbicides are available mostly for the broadleaf weeds in wheat. Annual grasses have increased in the spring wheat growing areas because of semidwarf wheats being grown and reduced tillage systems. Use of fertilizers has also increased weed problems.

Managing the Soil Surface for Intake and Storage of Water

The soil surface must be managed for maximum intake of water into the soil, for keeping the water on the land where it falls and for controlling runoff and water erosion. Wind erosion also must be controlled because fertility and valuable topsoil as well as the crop can be lost. Vegetative cover on the soil surface is the simplest and surest way of protecting the soil from wind and water erosion. At the same time it reduces runoff, reduces evaporation and improves infiltration of water into the soil. Mulching soil with plant residues increases water infiltration into the soil and reduces water runoff, wind erosion and moisture evaporation. In the Great Plains, more water is stored in the soil as the amount of residues on the surface of the soil is increased. When it rains, infiltration continues at a higher rate for a longer time with residue than with bare fallow. Yields are usually better with a stubble-mulch fallow in dry years. In the more humid region, yield reductions with residues are due to factors such as lower soil temperatures, poor weed control, and lower nitrogen availability because of more nitrate tieup by residue decomposition.

Barnes and Bohmont (1968) in Wyoming found that the water intake at the end of one hour was 1 cm for bare fallow, 3 cm for grassland and 5.7 cm for stubble-mulch. McCalla (1961) emphasizing the importance of mulches on soil structure, showed that surface mulch is more important than soil organic matter in increasing water infiltration. A subsoil devoid of organic matter and not mulched had a water intake of 1.1 cm per hour, while the mulched subsoil infiltration rate was 1.9 cm per hour for the same period of sprinkling. Infiltration in a good topsoil was 1.4 cm per hour for nonmulched, and 4.1 cm per hour for mulched, after 3 hours of sprinkling.

Stubble left upright over winter is very important to snow catchment and water conservation in much of the Great Plains. According to Greb, Smika and Black (1967) snow melt moisture is more than 66 percent effective, compared with 0 to 15 percent effectiveness of moisture from a July rainstorm.

Unger and Parker (1968) studied the effectiveness of stubble-mulch farming on water conservation during the fallow period. They found that mulches significantly enhanced water conservation during long dry periods. Evaporation from soil over a 16-week period was reduced 57 percent by straw applied and mixed with the

soil surface, and 19 percent by straw buried 3 cm deep. Other findings in Nebraska, Colorado and Montana showed a significant increase in fallow moisture efficiency with 1700 to 6700 kg/ha of surface straw mulch, compared with bare fallow.

At Alliance, Nebraska, stubble-mulch fallow was compared to bare fallow in a winter wheat-fallow rotation on a Keith very fine sand loam soil with a 4 percent slope. Soil loss (Table 2) was reduced 86 percent and runoff 60 percent with stubble. In growing winter wheat, soil loss was reduced 75 percent and runoff 43 percent by using stubble-mulch fallow. The effectiveness of stubble-mulch farming for conserving water during both the fallow and the growing season is significant.

Table 2. Runoff and soil loss produced from several fallow methods in a winter wheat-fallow rotation at Alliance, Nebraska, from 1958 to 1965.

	During fallow period		During growing period	
	Stubble mulch	Bare	Stubble mulch	Bare
Runoff (centimeters)	4.8	11.9	11.4	19
Soil loss (kg/ha)	3,800	24,500	9,970	39,000

An eight-year study at Alliance, Nebraska, evaluated the effects of stubble-mulch fallow, one-way disk fallow and bare fallow on wind erosion in a winter wheat-fallow rotation. Cultivation in the stubble-mulch fallow was primarily with large V-sweeps and a rodweeder. The one-way fallow plots had one operation with the one-way disk followed with several operations with a chisel plow equipped with 40 cm sweeps, then several operations with a rod-weeder. Bare fallow plots were plowed with a moldboard plow, then tilled several times with a field cultivator and rodweeder. Average results for the eight year period showed soil losses by wind erosion of 1.9, 3.1 and 6.5 metric tons/ha for stubble-mulch tillage, one-way disk fallow and bare fallow, respectively.

Chepil and Woodruff (1963) in a portable wind tunnel test on a number of winter wheat fields in the Nebraska Panhandle found that fallow tilled with a moldboard plow had an average annual soil loss of 24 metric tons/ha compared with 1.8 metric tons/ha for stubble-mulch fallow. The reduced erodibility on the stubble-mulched areas was due to larger amounts of surface residues--2,900 kg/ha on stubble-mulched compared with 680 kg/ha on clean tillage.

Tillage Equipment for Maintaining Surface Residue and Maximum Water Intake

The primary purposes of tillage are to control weeds, prevent

erosion and prepare a seedbed. However, tillage tends to destroy soil structure, reduce surface residues, and permit evaporation of moisture from the tilled layer of soil. Tillage machines used for conservation tillage are of two types: 1) those that stir and mix the soil, e.g., the one-way disk, offset disk, tandem disk, chisel plow and mulch treader; and 2) those that cut beneath the surface without inverting the tilled layers, e.g., the sweep plow, rodweeder with semichisel and rotary rodweeder.

Disk-type implements use a gang of disk blades 40 to 60 cm in diameter, spaced 20 to 25 cm apart. They operate at an angle to the direction of travel which gives a cutting and turning action to the soil. Disk-type implements bury from 30 to 70 percent of the residue on each trip across a field depending on the design of the specific implement and how it is operated. Increasing size, concavity, and spacing of disks and depth of operation all increase the amount of residue buried in each operation. Disk-type implements provide good weed control, but they bury considerable residue and remove it from the soil surface reducing erosion control.

Chisel plows are heavy tool carriers with high-clearance shanks usually spaced 30 cm apart. They can be equipped with 5 cm chisels or up to 50 cm shovel sweeps. The chisel plow kills weeds by partially inverting the soil, severing weed roots and drying out of the surface soil. The percentage of reduction of residue on each operation is usually about 25 percent. A rotary rod can be used behind the last row of shanks for improving weed control, leaves the surface smooth and retaining more residues on the soil surface.

Mulch treaders use a gang of wheels with curved teeth or chisels protruding. The wheels are 40 to 50 cm in diameter spaced 20 to 25 cm apart. They are operated in tandem gangs and at an angle to the direction of travel. Mulch treaders are used as a secondary tillage tool to improve weed control, especially shallow-rooted weeds. They are also used to distribute and anchor heavy residues and firm the seedbed prior to seeding. A disadvantage of the mulch treader is that it flattens and partially incorporates residues, and this hastens their decomposition.

Sweep plows are usually equipped with 75 cm or wider V-sweeps. The most common width of V-sweeps is 150 to 180 cm. The sweep blade ranges from 15 to 20 cm in width with about a 37 degree pitch for soil lift. The angle of the V-blade ranges from 60 to 100 degrees. Wide-angled sweeps penetrate the soil better, but the shedding of weed roots and residues is a problem that frequently requires less angle. On machines of more than 360 cm in width, each sweep must be flexible to achieve uniform tillage. To prevent clogging of standards in heavy residues or in bunchy residues, rolling coulters at least 50 cm in diameter and placed ahead of the sweeps are necessary. The major disadvantage of the subsurface tillage tools is lack of weed control, especially when grassy weeds exist under moist conditions. Sweep machines can be used for all of the fallow operations. Frequently, the last operation is performed with a rotary rodweeder.

A rotary rodweeder is equipped with a 2.5 cm square rod that operates under the soil surface. The usual depth of operation is 5 to 7 cm. The rod rotates opposite to the direction of travel for trash clearance and firming the soil. The rod is driven with a ground wheel, power takeoff or hydraulic motor. It is an excellent secondary tillage tool to firm the soil and control small weeds especially before seeding. Each operation of the rodweeder usually reduces the residue 5 to 10 percent.

Selecting Tillage Tools

No one set of tillage tools is best for all conditions. The kind, quantity, and quality of residues; number, kind and size of weeds present; moisture conditions; soil texture; length of fallow; and time of operation; width of equipment; concavity of disks; and width, pitch and angle of sweep blades are all factors in residue retention and weed control. Amount of stubble, height and length as well as its orientation also influence the amount of residue buried. Table 2 presents the average reduction of wheat residue for one tillage operation.

Selection of a tillage operation should be based on consideration of maximum moisture storage, efficiency of operation and residue maintenance. Weed control is a necessity for moisture conservation. Tillage is advisable when weeds consume more soil moisture than would be lost with a tillage operation. Where only a few weeds exist at harvest, the stubble is usually left until spring. If weeds exist in sufficient quantity to use moisture or set seed, tillage should be performed soon after harvest. Some weeds such as downy brome must be controlled early in the spring before seed is formed.

Proper Planting of the Crop

Planting of a crop is a very critical operation in dryland farming. The seed needs to be placed firmly into moist soil for rapid germination. The seedbed must be firm and mellow with ample moisture for germination and growth. Dates, methods and rates of planting must be adapted to the specific crops and location.

Date of Planting.--Date of planting in western Nebraska is an important consideration in controlling disease and insects. Yield loss results from either planting too early or too late. The optimum planting date gives time for good establishment of the wheat plant without serious loss of soil water or exposure to disease. Top growth of the plant supplements the effects of crop residues in controlling wind and water erosion. Planting too early will produce excessive top plant growth which utilizes valuable stored fallow moisture in unproductive fall growth. Early planted wheat is more susceptible to crown and root rot and to wheat streak mosaic which is carried by a microscopic leaf curl mite.

Delaying planting too long may prevent plants from becoming well established and makes them more subject to winter kill if winters are severe. Late planting may not produce adequate plant growth for effective wind erosion control. Wheat should be planted so it becomes well established without wasting valuable soil moisture. The same principles and dates for planting wheat can be applied to winter barley and rye.

Spring small grains in Nebraska and in the surrounding Great Plains states generally produce the highest grain yields when planted as early as soil conditions permit. Normally the spring small grains are planted in the early spring. Heat and moisture stress are likely to occur during the summer which can reduce yields.

Planting Equipment.--A seedbed should be sufficiently firm to provide good seed-soil contact and adequately moist to provide water for germination and seedling establishment. The soil moisture content and the amount of residue present at seeding time determine the best kind of plant equipment. The best drills are adaptable to a range of moisture and mulch conditions which are likely to be encountered. A drill that will be able to plant through a dry soil layer and/or crop residue mulch and place the seed into moist soil is essential for good vigorous stands. The seeds must be placed in moist soil so they can germinate quickly, thereby establishing the stand near the optimum date. In dryer areas, the expected thickness of dry soil will be greater than in the wetter climates, so a different drill may be required. Types of drills commonly used for seeding winter wheat are: 1) surface drills, usually single disk (may be double disk) drills with row spacings of 15 to 20 cm; 2) semi-deep furrow drills, usually single disks or small hoes spaced 23 to 25 cm apart; 3) deep furrow drills, usually hoes or shoes spaced 30 to 36 cm apart.

Surface drills with disk openers are used where small quantities of residue are on the soil surface at seeding time. Disk opener drills are commonly used in the continuous wheat producing areas where the plow is the primary seedbed preparation implement. Disk openers are also used by growers who practice black fallow methods where no or little residues are on the surface at seeding time. Semi-deep and deep furrow drills are used for one or more of the following reasons: 1) Planting in furrows enables the grower to seed through a much thicker layer of dry soil than is possible with a disk drill. This is especially advantageous in the dryer areas. 2) Planting in furrows provides a rough soil surface which aids in wind erosion control. 3) Planting in furrows with hoe openers permits the grower to plant in mulched soils that result from stubble-mulching tillage practices. This planting technique preserves the maximum amount of surface residues and anchors them securely for maximal wind erosion control. Furrow drills with large disks may also be satisfactorily used to plant in mulched soils. 4) Wheat drilled in furrows is better protected against winter kill. Few specifications are necessary with disk opener

drills because seeding is done in a "clean" seedbed where no residues or weeds are present. Seeding in a mulch system, however, will be easier if the semi-deep and deep furrow drills meet the following specifications: 1) at least 50 cm of clearance between ranks of openers; 2) at least 46 cm of vertical clearance between the tip of the hoe and the attachment of the hoe to the frame; 3) row spacing of 25 to 36 cm, wider rows for heavier residues; 4) shoe or hoe opener width of not more than 10 cm; and, 5) press wheels that pack the soil firmly and anchor residues in the ridge. Enclosed convex press wheels have proved very satisfactory. Flexibility is necessary with any of the three types of drills if they are to be used on fields where the surface is irregular. Drills which flex in 1.8 and 2.7 m sections are very desirable, especially on terraced land.

Row Spacing.--Wheat is usually drilled in rows spaced from 15 to 41 cm apart. Research in the Great Plains and Canada has shown that row spacing has little influence on grain yields. There are, however, other factors to consider in choosing a row spacing. The wider spacings (30 to 41 cm) have the following advantages: 1) permit deeper furrows and the placing of seed in moist soil even where the surface soil is dry without excessive soil falling into the rows; 2) provide a potential for increased surface roughness for erosion control if the furrows are deep; 3) provide more trash clearance in heavy residue conditions; and, 4) less initial cost and maintenance expense. The wider rows provide less shading of the soil which favors weed growth in the spring.

Seeding Depth.--Depth of soil over the seed is very important. Seed must be placed firmly in moist soil and covered with sufficient soil to prevent rapid drying. Depth of soil over the seed should be 2.5 to 4 cm in medium to fine textured soils and 5 cm for coarse textured soils. Seed should never be covered more than 8 cm. Wheat seedlings covered with more than 5 cm of soil definitely lose vigor. They often fail to emerge or, if they do emerge, they are more susceptible to winter kill or disease. Deep or semi-deep furrow drills are advisable in areas where the surface soil may be dry at planting. They allow placement of the seed in moist soil without excessive soil covering over the seed.

Ecofallow (Chemical Fallow)

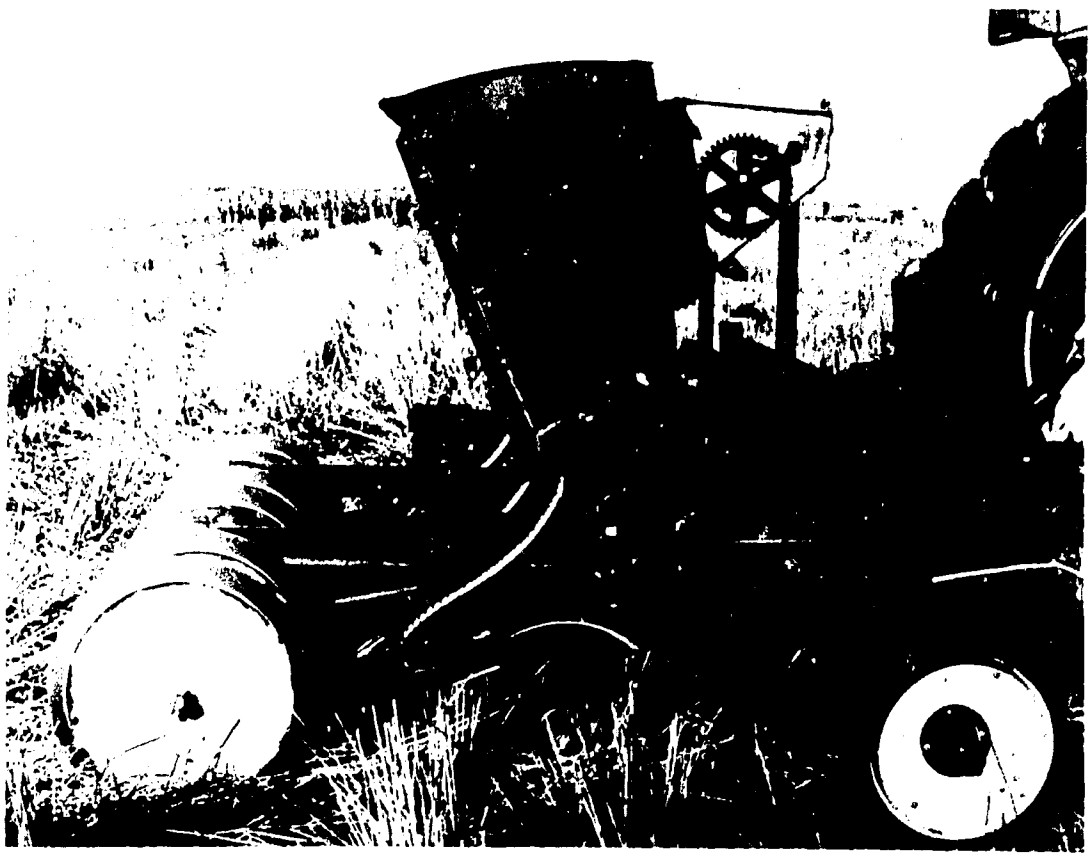
Frequently, low amount of vegetative residues are produced due to factors such as drought, hail, disease or other pestilence. When residue quantities are low, troublesome weeds are present. The maintenance of enough residues on the soil surface for a protective cover is difficult with tillage. The use of herbicides to replace all or part of tillage operations aids in the maintenance of plant residues. By reducing the number of tillage operations, herbicides reduce energy requirements and improve the physical conditions of the soil.

In Nebraska, a system of controlling weeds and conserving soil

moisture in a crop rotation is called "ecofarming". Weed control is obtained with herbicides or a combination of herbicides and subsurface tillage operations. Recent studies in Kansas and Nebraska indicate that where adequate weed control is obtained with herbicides, moisture conservation and crop yields are as good or better than with conventional fallow methods.

At North Platte, Nebraska, Wicks and Smika (1973) used a winter wheat-fallow rotation during a six-year period to compare no tillage and herbicides to conventional tillage. The plots receiving no tillage (weeds controlled by herbicides) had the least weed growth, the most soil water stored, the highest amount of surface mulch and the highest grain yields of all the fallow treatments. The bare fallow treatments yielded 2,400 kg/ha, stubble-mulch fallow yielded 2,570 kg/ha, and the no-till fallow yielded 2,640 kg/ha. At Sidney, Nebraska, Fenster and Peterson (1979) using a winter wheat-fallow rotation and three methods of fallow during an eight-year period, bare fallow averaged 2,440 kg/ha, stubble-mulch fallow 2,500 kg/ha, and no-till fallow averaged 2,580 kg/ha. Stubble-mulch fallow with ecofallow in a winter wheat-sorghum and in a winter wheat-corn fallow rotation was also compared. Higher sorghum and corn yields were obtained with ecofallow. Over 300,000 hectares of corn and sorghum are now grown in Nebraska, Colorado, and Kansas using herbicides as a substitute for tillage.

The ecofallow system is being accepted as a sound conservation practice to conserve moisture, soil, and energy. The practice will grow as we learn more about weed control application of herbicides, soils and their relationship to herbicides and the development of seeding equipment for heavy residues.



References

Barnes, O. K. and D. W. Bohmont. 1958. Effect of cropping practices on water intake rates in the northern Great Plains. Wyo. Agr. Exp. Stn. Bull. 358.

Boosalis, M. G. and G. D. Cook. 1973. Plant diseases. In Conservation Tillage. Soil Cons. Soc. Am., Ankeny, Iowa.

Black, A. L. 1973. Soil property changes associated with crop residue management in a wheat fallow rotation. Soil Sci. Soc. Am. Proc. 37(6):943-946.

Chepil, W. S. and N. P. Woodruff. 1963. The physics of wind erosion and its control. Advances in Agron. 15:211-302.

Duly, F. L. and C. R. Fenster. 1960. Stubble-mulch farming methods for fallow areas. University of Nebraska E.C. 54-100, Lincoln. 19 pp.

Fenster, C. R. 1960. Stubble mulching with various types of machinery. Soil Sci. Soc. Am. Proc. 24:518-523.

Fenster, C. R. 1960. Stubble mulching controls runoff. Nebr. Agr. Exp. Stn. Quart. 6(4):3-4.

Fenster, C. R. 1977. In the Great Plains Conservation Tillage. Soil Cons. Soc. Am., Ankeny, Iowa. pp. 37-42.

Fenster, C. R. and G. A. Peterson. 1979. Effects of no-tillage fallow as compared to conventional tillages in a wheat-fallow system. Nebr. Agr. Exp. Stn. RB 289. 28 pp.

Fenster, C. R. and T. M. McCalla. 1970. Tillage practices in western Nebraska with a wheat-fallow rotation. Nebr. Agr. Exp. Sta. Bull. 597. 20 pp.

Fenster, C. R., G. A. Wicks, and D. E. Smika. 1973. The role of ecofallow for reducing energy requirements for crop production. Agron. Abstr. 64:122.

Greb, B. W., D. E. Smika, and A. L. Black. 1967. Effect of straw mulch rates on soil water storage during summer fallow period in the Great Plains. Soil Sci. Soc. Am. Proc. 31:556-559.

Greb, B. W. 1979. Reducing drought effects on cropland in west central Great Plains. USDA Information Bull. No. 420. 31 p.

Haas, H. J., W. O. Willis, and J. J. Bond. 1974. Summer fallow in western United States. Cons. Res. Rpt. No. 12. USDA/ARS, Washington, D.C. 160 pp.

Hanway, D. G. 1979. Ecofarming concept in multiple grain rotations with minimum tillage in semi-arid climates: Impact on semi-arid agriculture. Presentation at IX International Congress for Pest Management, Washington, D.C.

Irving, G. W. Jr., and E. L. LeClerg. 1965. Losses in agriculture. Agr. Handbook No. 291. USDA, Washington, D.C.

Jacks, G. V., W. D. Brind, and R. Smith. 1955. Mulching. Tech. Comm. No. 49. Commonwealth Bur. Soil Sci., London, England.

McCalla, T. M. and T. J. Army. 1961. Stubble-mulch farming. Advances in Agron. 13:125-196.

Nalewaja, J. D. 1972. Weeds coexistence or control. J. Environ. Qual. 1:344-349.

Reitz, L. D. 1976. Wheat in the United States. USDA Information Bull. No. 386. 57 p.

Unger, P. W. and J. J. Parker Jr. 1968. Residue placement on decomposition, evaporation, and soil moisture distribution. Agron. J. 60:469-472.

Wicks, G. A. and D. E. Smika. 1973. Chemical fallow in winter wheat-fallow rotation. Weed Sci. 21:97-102.

Woodruff, N. R., C. R. Fenster, W. W. Harris, and M. Lundquist. 1966. Stubble-mulch tillage and planting in the Great Plains. Trans., ASAE 9:849-853.

Zingg, A. W. and C. J. Whitfield. 1957. A summary of research experience with stubble-mulch farming in western states. USDA Tech. Bull. 1166. Washington, D.C.

WEED CONTROL IN RAIN-FED WHEAT

Arnold P. Appleby
United States

Because of limited time for a very broad subject, I have chosen to restrict my remarks to three general concepts concerning weed control in wheat.

Herbicide availability. I have attempted to find out the number of herbicides actually available for use in small grains in the world. Although I do not claim that this list is completely accurate, I was able to find at least 48 compounds which are being used on wheat, or have recently been used somewhere in the world (Table 1). I might have missed a few in my search. So, although there are many unsolved problems remaining, I am sure you will agree that the field has been quite active in recent years and that there are many tools available, even now. Furthermore, several promising new herbicides are being tested for possible commercial use. Some of these involve entirely new types of chemistry and levels of activity. One new experimental compound, DPX 4189, is controlling a number of broadleaf weeds at rates as low as 2 to 4 g/ha.

Increasing use of herbicides. There has been an increase in the use of herbicides in wheat and I believe there are several reasons for this. Plant ecosystems are very resilient. If a constant pressure of some sort is applied, such as continuing use of a particular herbicide or family of herbicides, to eliminate a certain species, different species or different biotypes, which are resistant to that pressure tend to become dominant. For example, since phenoxy herbicides were introduced in the mid-1940's, there has been a steady increase in grass weeds in small grains. An example is the continual expansion of wild oats in large areas of the wheat-producing regions in the world. We believe that this shift in species can often be largely overcome by wise use of (a) crop rotations, (b) good cultural management practices, and (c) herbicide rotations to help prevent the build-up of resistant weeds.

Our wheats are yielding higher than they used to and therefore we can afford to buy more herbicides. We collected yield data from the use of diclofop methyl at 21 locations over a 5-year period in western Oregon (Table 2). Primary weeds were *Lolium multiflorum* and *Avena fatua*. Although yields varied from year to year, the treatments caused dramatic increases in yield each year. In spite of the fluctuation in yield from year to year due to plant diseases, winter damage, etc., we obtained an average yield increase of 2500 kg/ha. At $150/metric ton, this represents a gross increase in income to the grower of $375/ha. Of course, western Oregon is not representative of many areas of rain-fed wheat. It is a high-yielding area, but the fact remains that as yields go up, the number of kg/ha which can be lost to weeds also goes up, making the use of herbicides a better investment.

Oregon State University, Corvallis

Table 1. Herbicides used in wheat and barley.

1. barban	17. dinoterb	33. metoxuron
2. benazolin	18. dinoseb acetate	34. metribuzin
3. benzoylprop ethyl	19. diuron	35. monolinuron
4. bromofenoxim	20. flamprop isopropyl	36. neburon
5. bromoxynil	21. 1-flamprop isopropyl	37. paraquat
6. chlorbromuron	22. flamprop methyl	38. phenothiol
7. chlorfenprop methyl	23. ioxynil	39. picloram
8. chlortoluron	24. isomethiozin	40. propanil
9. clofop isobutyl	25. isoproturon	41. terbuthylazine
10. cyanazine	26. lenacil	42. terbutryn
11. diallate	27. linuron	43. triallate
12. dicamba	28. MCPA	44. trifluralin
13. dichlorprop	29. MCPB	45. trimeturon
14. diclofop methyl	30. mecoprop	46. 2,4-D
15. difenzoquat	31. methabenzthiazuron	47. 2,4,5-T
16. dinoseb	32. methaprotryne	48. 2,4-DB

Table 2. Influence of diclofop methyl on wheat yields at 21 locations in western Oregon.

Year	No. of Locat.	Avg Wheat Yield (kg/ha) Diclofop	Untrted Ck.
1975	6	6500	3400
1976	4	6100	2500
1977	4	5200	3000
1978	3	4000	2500
1979	4	8500	7100
	Avg =	6200	3700

I believe that people are gradually becoming more aware of the benefits of weed control. Our extension service workers and the chemical industry representatives are doing an excellent job of explaining these benefits.

Perhaps a minor reason for more herbicide use is that some of the more recent herbicides can be used where phenoxys cannot be used because of potential drift problems.

Integration of herbicides and other practices. The third major subject that I wish to discuss today is the intergration of these powerful herbicide tools with other agronomic practices. One of these practices is the use of nitrogen fertilizer. Yield data from experiments we conducted a few years ago illustrate an important point (Table 3). When weed control practices were carried out, but nitrogen application was insufficient, little or no benefit was obtained from controlling weeds. At the same time, when nitrogen fertilizer was applied to plots in which weeds were not controlled, little or no benefit from nitrogen was obtained.

Table 3. Interaction of weed control and nitrogen fertilizer on wheat yields in western Oregon.

N Level (kg/ha)	Yield (kg/ha) Weeds Controlled	Weedy	Reduction %
0	4860	4860	0
40	6100	5010	8
80	6530	5300	19
120	6680	4860	28

Optimum yields were obtained only when both weed control practices and adequate fertilizer treatments were applied. Table 4 shows similar data with an added variable. Also included in these competition studies were two cultivars. These included Nugaines, a semi-dwarf, and Druchamp, a taller variety. Nugaines was considerably more susceptible to competition from the weeds than the taller Druchamp. As nitrogen fertilizer increased, the percentage reduction in yield due to weeds increased in both cultivars. With both cultivars, the addition of higher amounts of nitrogen actually caused a reduction in yield in the weedy plots. The weeds responded to the fertilizer as well or better than did the wheat, and the result is a complete waste of resources by application of nitrogen when weed control practices were not carried out.

Table 4. Interaction of cultivar, weed control, and nitrogen fertilization on wheat yields in western Oregon.

Cultivar	N Level (kg/ha)	Yield (kg/ha) Weeds Contr.	Weedy	Reduct. (%)
Nugaines	50	3070	1920	38
(semi-dwarf)	100	3570	2000	44
	150	3450	1720	50
Druchamp	50	3680	2960	19
(tall)	100	3990	3180	20
	150	4150	2840	32

Herbicides should be considered only as one tool interacting with other cultural methods. Moldboard plowing can be helpful in the control of certain grass weeds which have short persistent seeds, such as many of the brome species. Large numbers of seeds can be destroyed simply by burying them and allowing them to decompose over time. Moldboard plowing also reduces trash on the surface and allows soil-active herbicides to be more efficient.

At the other end of the scale, there is a definite trend toward non-tillage methods. These systems depend heavily on foliage-active herbicides such as paraquat, glyphosate, and others.

Intermediate between these two systems is the use of herbicides as an "aid to tillage" in a reduced tillage system. In a wheat fallow system, summer tillage would still be used but the control of fall- and winter-germinating weeds would be done

early with the use of herbicides. If we allow winter weeds to grow until they could be removed by spring tillage, significant amounts of moisture would already be lost. Also, with herbicides, summer tillage can be delayed, thus saving trips over the field and reducing petroleum usage. This delay in tillage also could help produce soil erosion.

I have discussed primarily herbicides today but please keep in mind that herbicides are not the only weed control technique. We encourage the use of all other techniques, including such things as crop rotation, timely use of tillage, competitive cultivars, use of clean seed, the use of clean equipment for harvesting and tillage, and even hand-weeding in those areas where weeds are sparse and labor is readily available.

With the intelligent use of present weed control methods and the prospects of exciting new experimental compounds, we can be optimistic about the long-term future of weed control in wheat!

References

Appleby, A.P., P.D. Olson, and D.R. Colbert. 1976. Winter wheat yield reduction from interference by Italian ryegrass. Agron. J. 68:463-466.

Brewster, B.D., A.P. Appleby, and R.L. Spinney. 1977. Control of Italian ryegrass and wild oats in winter wheat with HOE 23408. Agron. J. 69:911-913.

ACCELERATED WHEAT PRODUCTION IN SEMI-ARID DEVELOPING AREAS: ECONOMIC AND POLICY ISSUES

D. Byerlee and D. Winkelmann
Mexico

Abstract

Means for accelerating wheat production in the semi-arid wheat producing areas of North Africa, the Middle East, and Asia (i.e., Morocco to Bangladesh) will be reviewed. First, the recent story of trends in wheat production, area, yields and imports are reviewed to show that, although some countries such as Turkey have recently experienced dramatic expansion in production, wheat production in most countries has lagged well behind demand increases, resulting in substantially increased imports of wheat. Given the importance of wheat as a source of calories in these countries, the continuation of these trends will result in even higher level of imports in the 1980's. Wheat-producing regions are then classified into areas in which moisture is generally adequate and semi-arid areas in which moisture is usually limiting. Average yields and the importance of bread wheats and durum wheats in each area are examined. This overview of wheat production and consumption trends in semi-arid developing areas concludes with evidence from yield potentials from experimental stations, experiments in farmers' fields and the record of increased yields in semi-arid areas of Australia and the USA indicating that, except in the driest areas, wheat yields can be significantly increased.

Factors that condition a farmer's decision to adopt new technologies in semi-arid areas and the relevance of some technological components will be examined. The farmer is projected as allocating his limited resources within a complex farming system (usually including livestock) to satisfy his goals of income, food security, and risk avoidance. Within this framework, evidence of the appropriateness of weed control, fertilizer and variety technologies to farmers in semi-arid areas is discussed. In areas where research has been extensively conducted in farmers' fields, technologies to increase farmers' income and yields are available although costs and factors such as the use of weedy fallow for livestock and the level of risk involved in nitrogen use will often lead to use of technologies and yields well below those potentially available. The experiences of technological change in semi-arid wheat producing regions show that with adequate information and availability of inputs farmers have rapidly adopted improved technologies although the adoption tends to proceed step by step rather than adoption of full "packages".

The paper concludes with some implications for research and policy. Given the importance of crop management versus variety,

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there is a need to substantially increase on-farm agronomic research in the region, both to generate recommendations for farmers and also to provide information to policy makers. Such research might benefit from early integration of agricultural economists. Policy issues condition the environment in which farmers operate. Contrary to general belief, the price incentives for wheat production, fertilizer use and wheats versus livestock are found to be generally favorable in relation to such large scale producers as Australia and the USA.

This paper, focusing on wheat production in the semi-arid regions (SAR) of selected developing countries, is divided into three main parts. We begin by providing a perspective on what has happened in wheat production in the recent past, particularly in SAR's, and follow with evidence on projected demand increases and the potential for increasing wheat production in these areas. The second section then analyzes economic considerations affecting farmers' choices among alternative technologies again with particular reference to the SAR's. We conclude by drawing some implications for agricultural research and policy.

1.0 Trends in Wheat Supply and Demand: The World and the SAR's

1.1 Trends in World Wheat Production and Prices -- Changes in the world's production of wheat, wheat yields, and international trade in wheat have exceeded world population growth over the past two decades (see Table 1). Similar data for maize and rice show changes in yield lagging well behind wheat. For maize only area changes have permitted production increments to keep pace with those of wheat. The price data of Table 2 show that wheat's real price (its dollar price adjusted for changes in the U. S. price level) has declined since the first half of the 1960's. Also, as a consequence of the more rapid production increases in wheat, the price of wheat relative to that of rice has declined over the 1960's and '70's. Interestingly, even though maize and wheat production changes were virtually identical over the period, the price of maize relative to that of wheat has risen markedly, from .69 to .84 or by some 20 percent.[1/] This is largely a consequence of the large and growing demand for maize for animal feed, as a consequence of rapid increases in the consumption of livestock products with rising incomes.

For wheat, the inference from the price data is that production changes have exceeded changes in demand emanating from population increases, from income changes, and from changes in other prices. From the standpoint of the consumer, this reduction in real prices reflects well on the efforts of the wheat industry.

1.2 Trends in Wheat Production for Selected Countries and Regions -- Table 3 presents details for developing countries which produce more than 100,000 hectares of wheat.

[1/] This ratio is down a bit, to about .75, in the most recent months.

Table 1. Measures of world area, yield and production for wheat, maize and rice (1961-1978).

	Area[a]		Yield[a]		Production[a]		Trade[a]		Annual Rate Change (1961-1978)			
	1961-65	1974-78	1961-65	1974-78	1961-65	1974-78	1961-65	1974-78	Area	Yield	Prod.	Trade
	(1000 ha)		(ton/ha)		(1000 ton)		(1000 ton)		(Percent/Year)			
Wheat	210.4	230.4	1.2	1.7	254.4	392.4	54.0	70.5	.7	2.7	3.4	2.3
Maize	99.7	116.2	2.2	2.9	216.4	332.7	20.4	57.8	1.2	2.1	3.4	8.4
Rice[b]	123.6	142.2	2.0	2.5	253.2	355.4	7.3	9.2	1.1	1.5	2.6	1.8

[a]Data for five-year averages.
[b]Paddy.

Source: FAO Production Yearbooks and FAO Trade Yearbooks 1970 and 1978.

Table 2. Selected prices for wheat, maize, and rice[a], 1961-1978 (dollars/ton).

	Current dollars		Constant 1967 dollars[b]		Ratio of price of maize and rice to wheat prices	
	1961-65	1974-78	1961-65	1974-78	1961-65	1974-78
Wheat	70.2	119.9	76.0	68.2	1.0	1.0
Maize	49.0	102.1	52.7	57.3	.69	.84
Rice	141.8	358.4	154.4	215.1	2.03	3.15

[a]Prices are five-year averages centered on 1963 and 1976.
[b]The U. S. CPI has been adjusted to reflect differences between calendar and crop years for maize and for wheat.

Table 3. Selected wheat statistics by country and region, 1961-1978.[a]

Region and Country	Area 1961-65	Area 1974-78	Yield 1961-65	Yield 1974-78	Net Imports 1961-65	Net Imports 1974-78	Annual Rate of Change: Area	Yield	Production	Imports
	(1000's has)		(Tons/ha)		(1000's tons)		(Percent)			
North Africa	4700	5239	.66	.73	950	3876	.9	.8	1.7	11.4
Algeria	1072	2125	.64	.60	339	1747	.5	-.5	[illegible]	[illegible]
Libya	149	211	.25	.39	137	490	2.7	3.5	6.2	10.3
Morocco	1578	1843	.85	.93	322	1277	1.2	.9	2.1	11.0
Tunisia	1002	1060	.49	.72	152	332	.6	3.0	3.6	7.3
Other Africa	1615	1579	1.41	1.66	1872	4160	-.2	2.2	2.0	6.4
Egypt	557	568	2.62	3.35	1747	3890	.2	1.9	2.1	6.4
Ethiopia	928	636	.71	.89	22	77	-2.9	1.6	-1.1	10.1
Kenya	103	114	1.18	1.46	-2	45	.6	1.8	2.6	c/
Sudan	27	261	1.31	1.13	105	165	19.1	-1.1	16.0	3.5
Middle East	16773	10270	.95	1.30	1244	2758	1.5	2.4	3.9	6.3
Afghanistan	2321	2346	.95	1.20	46	20	0.1	1.8	1.9	-6.2
Iran	3560	5585	.60	.69	193	1270	3.5	1.7	5.2	15.3
Iraq	1210	1296	.70	.79	156	709	.1	.9	1.0	12.4
Israel	58	106	1.54	2.11	257	440	4.7	2.5	7.2	4.2
Jordan	249	146	.72	.66	113	216	-4.0	-.7	-4.7	5.1
Syria	1396	1580	.78	.99	-73	355	1.0	1.9	2.9	d/
Turkey	7959	9220	1.08	1.64	552	-212	1.1	3.3	4.4	d/
South Asia	18555	20466	.84	1.36	5774	6197	2.9	3.8	6.6	.5
Bangladesh	60	152	.51	.38	na	1419	7.4	6.5	13.9	na
India	13402	19824	.84	1.36	4301	3540	5.1	3.9	6.9	-1.8
Nepal	109	324	1.24	1.12	0	41	8.7	-.3	7.6	d/
Pakistan	4984	6156	.83	1.35	1273	1197	1.6	3.8	5.4	na
Latin America	7889	9456	1.46	1.48	-239	2146	1.7	.1	1.8	d/
Mexico	802	783	2.09	3.55	-235	382	-.2	4.2	4.0	d/
Argentina	1916	4914	1.33	1.58	-3207	-2608	0.0	.2	.2	-.3e/
Brazil	812	1021	.71	.83	2152	[illegible]	10.6	1.2	11.8	2.5
Chile	753	653	1.44	1.55	190	922	-1.2	.6	-.7	12.9
Peru	153	131	.98	.89	406	766	-1.2	-.7	-1.9	5.0
Uruguay	453	374	1.03	.97	-25	-27	-1.5	-.5	-2.0	.6e/
Selected Other										
China	25195	30601	.88	1.35	4477	5695	1.5	3.3	4.8	1.9
U. S. S. R.	66422	61254	.90	1.55	10	3489	-.6	3.5	2.9	5.7
Major Exporters b/	41558	50520	1.66	2.06	-39465	-59237	1.4	1.7	3.1	3.2e/

a/ Data are for five-year averages for 1961-65 and 1974-78.
b/ Includes Australia, Canada, France, U.S.A.
c/ Growth rate is for exports.
d/ Growth rate not calculated because of change from importer to exporter or vice-versa.
na = not available.

Source: FAO Production and Trade Yearbooks.

It is clear that notable progress has been made in the last decade and a half in increasing yields. We choose to concentrate on yields rather than on production because, in the final analysis, a minimum goal must be to ensure that yields themselves keep pace with population changes. The data in Table 4, taken from Table 3, show the area and proportion of wheat in developing countries grouped by progress in yields. For 72 percent of the wheat area considered annual yield increases exceeded three percent and exceeded population changes. That is dramatic evidence of remarkable achievement.

Table 4. Area in wheat for developing countries[a] grouped by rates of change in yield over the period 1961-1978.

Annual yield changes (1961-78)	No. of countries in group	Area, 1978	Percent of total area
		(1000's ha)	
Over 3 percent	8	68,037	72
2-3 percent	1	106	-
1-2 percent	7	13,849	15
Under 1 percent	10	12,139	13
Total selected countries	26	94,131	100

[a]Developing countries with over 100,000 ha of wheat, including China.

Source: Calculated from Table 3.

There is, however, some 28 percent of the reported area where yield changes fell well below population changes. For the most part, this area is in the traditional wheat belt, much of it semi-arid, of the old world, from Morocco to Afghanistan.

Looking back at Table 3 it is evident that excellent progress on yields and production was made in Bangladesh, China, India, Libya, Mexico, Pakistan, Tunisia, and Turkey -- eight of the 26 developing countries reported. Most of these countries have a high proportion of their area sown to HYV's as shown in Table 6. For 17 of the countries, annual yield changes were below to two percent. Area changes were most notable in South Asia where yield changes were also large.

As another manifestation of further opportunity for progress, look at Table 3's import data. Twenty-three of the 26 developing countries listed were net importers over the period from 1974-78 and for 22 countries, net imports had increased over 1961-65. Indeed for 15 of the 26 countries even relative dependence on imports (imports as a percent of disappearance) had increased (see Table 5). Only Turkey and, by 1978, India, two of the largest producers among the 26 developing countries of Table 3, have become self-sufficient, and have entered the list of developing country exporters.

Table 5. Imports of wheat as a proportion of disappearance (production plus imports), for selected countries and regions, 1961-1978[a].

	Proportion Imported 1961-65	1974-1978		Proportion Imported 1961-65	1974-1978
North Africa	.23	.50	South Asia	.27	.15
Algeria	.21	.58	Bangladesh	na	.87
Libya	.79	.86	India	.29	.12
Morocco	.19	.42	Nepal	-	.10
Tunisia	.24	.33	Pakistan	na	.13
Other Africa	.45	.59	Latin America	b/	.13
Egypt	.54	.67	Mexico	b/	.12
Ethiopia	.03	.12	Argentina	b/	b/
Kenya	b/	.21	Brazil	.79	.54
Sudan	.75	.36	Chile	.15	.48
			Peru	.73	.87
Middle East	.07	.09	Uruguay	b/	b/
Afghanistan	.02	.01			
Iran	.06	.18	China	.17	.12
Iraq	.16	.41			
Israel	.74	.66			
Jordan	.39	.69			
Syria	b/	.19			
Turkey	.06	b/			

a/ Five-year averages, 1961-65 and 1974-78.
b/ Self-sufficient or exporter.

Source: Calculated from Table 3.

1.3 Classification into Various Wheat Production Regions -- Focusing more sharply on production in the SAR's of developing countries, attention is concentrated on developing countries from Morocco to Bangladesh which are significant producers of wheat. In the past, discussion about wheat production under various climate circumstances has been hampered by lack of data. For most countries, data have not been available for SAR's, but only for political sub-divisions. In collaboration with national programs and others, CIMMYT has assembled a first rough measure of wheat producing regions classified by moisture conditions and by type of wheat[1] (see Tables 7-9). The countries considered include a substantial part of the semi-arid production of developing countries. (Some 4 million hectares are produced in Latin America under roughly semi-arid conditions and beyond that there are substantial areas in China and Mongolia. Our data do not yet extend to these countries.)

1/ Our intent is to refine these data -- yields, area characteristics, and breeding issues -- and to then use CIMMYT nursery data as a basis for amalgamating regions across countries, arriving finally at several roughly homogeneous but not necessarily contiguous breeding environments.

Table 6. Area under HYV wheats for selected developing countries, 1978.

	Year	Area in HYV	HYV as percent of total wheat area
		(1000's has)	
North Africa			
Algeria	1976/77	300	15.7
Morocco	1972/73	254	11.6
Tunisia	1976/77	228.4	21.9
Other Africa			
Egypt	1976/77	125.5	24.7
Sudan	1977/78	147.6	49.2
Ethiopia	1976/77	150	27.2
Kenya	1976/77	23.3	19.4
Middle East			
Iraq	1974/75	750	53.3
Iran	1975/76	140	2.5
Syria	1976/77	362.8	23.7
Turkey	1976/77	2200	23.5
Afghanistan	1976/77	770	32.8
Jordan	1976/77	12	9.5
South Asia			
Bangladesh	1977/78	161.9	80.2
India	1977/78	15000	70.7
Nepal	1977/78	254.2	70.6
Pakistan	1976/77	4605.5	72.1
Latin America			
Mexico	1976/77	785	87.8
Argentina	1976/77	1930	49.4
Brazil	1974/75	650	22.2
Chile	1977/78	15	0
Peru	1976/77	0.4	0

Source: Dalrymple, D. G., Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations, USDA, 1978.

Tables 7-9 show that there are several different worlds for wheat. One evident world, with roughly half the area and well over half the production, is that of irrigated spring bread wheat. Some 90 percent of that wheat is in South Asia -- Bangladesh, India, Pakistan and Nepal.

The next large block is spring bread wheat in semi-arid regions followed by semi-arid winter wheat and then by semi-arid durum wheats. Yields in these regions apparently range from 0.6 to one ton per hectare. It is probable, however, that these estimates overstate current

Table 7. Selected wheat statistics by class of wheat and moisture regimes for selected developing countries, 1978.

Moisture Regime and Country	Class of Wheat: Spring Bread (1000 ha)	Spring Bread (ton/ha)	Durum (1000 ha)	Durum (ton/ha)	Winter Bread (1000 ha)	Winter Bread (ton/ha)
Irrigated:						
Morocco	48	2.7	68	2.3		
Libya	15	2.0				
Sudan	245	1.4				
Egypt	535	3.1	19	3.3		
Jordan			5	1.5		
Syria	130	2.4	42	2.3		
Iraq	86	1.2	65	1.2		
Iran	375	2.4			1170	1.9
Afghanistan	1125	na			125	na
Pakistan	4948	1.6				
India	14970	2.2				
Nepal	233	1.0				
Bangladesh	61	1.8				
Well-Watered:						
Morocco	227	1.1	1143	.9		
Algeria	380	1.0	670	.8		
Tunisia	80	1.2	586	1.0		
Libya	20	1.0	30	1.0		
Ethiopia	40	1.2	335	1.0		
Kenya	108	na				
Jordan			18	1.0		
Syria	300	1.4	116	1.0		
Turkey	1372	3.0	944[a]	1.6	1491	1.9
Iraq	191	0.9	150	0.9		
Iran	350	1.7	10	0.6	800	0.7
Afghanistan	65	na	10		135	na
Pakistan	252	1.1				
India	580	1.7				
Nepal	114	1.1				
Bangladesh	124	1.8				
Semi-Arid:						
Morocco	247	0.4	291	0.6		
Algeria	400	0.8	700	0.6		
Tunisia	20	0.8	584	0.8		
Libya	25	0.4	160	0.4		
Ethiopia	10	0.7	115	0.7		
Jordan			130	0.7		
Syria	64	0.9	860	0.7		
Turkey	436	1.8	1295[a]	0.6	3488	1.5
Iraq	877	0.7	150	0.7		
Iran	200	0.4	20	0.5	3000	0.5
Afghanistan	40	na	200	na	600	na
Pakistan	1417	0.9				
India	3710	1.0	1400	0.6		

[a] Both spring and winter durums are included.
na = not available.

Source: CIMMYT survey of national wheat programs.

yields and we fully expect that continuing attempts to refine the country reports underlying Tables 7-9 will lead to reductions in yields to something like 0.5-0.6 tons per hectare.

Unfortunately we do not yet have a measure of rates of changes of yields in these various producing regions[1/]. However, we do know that with the exception of Turkey most of the HYV's are spring bread wheats and it seems likely that most are found on irrigated or well-watered areas. One inference is that, for the most part, little change in yield has occurred in SAR's.

1/ We should point out that an exploratory effort to relate yield changes to the proportion of wheat irrigated, to the proportion well-watered, and to the proportion in spring bread wheat showed no statistical relationships of any significance.

Table 8. Selected wheat statistics by region, class of wheat and moisture regime, 1978.

Region and Moisture Regime	Spring Bread		Durums		Winter Bread	
	Area (1000 ha)	Yield (ton/ha)	Area (1000 ha)	Yield (ton/ha)	Area (1000 ha)	Yield (ton/ha)
North Africa						
Irrigated	63	2.5	68	2.3	-	-
Well-watered	757	1.0	2429	0.9	-	-
Semi-arid	692	0.6	1735	0.6	-	-
Other Africa						
Irrigated	770	2.6	19	3.3	-	-
Well-watered	148	1.2	335	1.0	-	-
Semi-arid	10	0.7	115	0.7	-	-
Middle East[a/]						
Irrigated	1716	1.6	112	1.6	1925	1.4
Well-watered	2278	2.2	1248	1.4	2426	1.4
Semi-arid	1617	0.9	2655	0.6	7088	1.0
South Asia						
Irrigated	20212	2.0	-	-	-	-
Well-watered	1070	1.5	-	-	-	-
Semi-arid	5127	1.0	1400	0.6	-	-

a/ Data for Middle East is especially rough because of estimates for Afghanistan.

Source: Calculated from Table 6.

Table 9. Area in wheat by class of wheat and moisture regime, 1978.

Moisture Regime	Class of Wheat			
	Spring Bread	Durum	Winter Bread	
		(1000 ha)		
Irrigated	22,771	199	1,295	24,255
Well-watered	4,253	4,012	2,426	10,691
Semi-arid	7,446	5,905	7,088	20,439
Totals	34,470	10,116	10,809	55,385

Source: Calculated from Table 6.

1.4 Trends in Demand for Wheat -- Wheat is the basic staple for the countries of the Middle East and North Africa and a significant staple for much of South Asia (see per capita consumption figures of Table 10). Consumer demand for wheat is determined by three factors - change in population, change in incomes and prices and people's propensity to increase wheat consumption with increases in income or reduced prices. On the first of these, it is clear that over most of the region wheat demand will expand by 2.5 percent per year or more due simply to population changes. Moreover, consumer preferences for wheat for direct consumption are well known. For most of the countries, changes in consumption relative to income changes are high and income changes vary from "notable" in oil-producing countries to "appreciable" in others.

Recent changes in wheat consumption reflect these forces. Estimated as the sum of wheat production plus imports, wheat consumption over the period 1961-78 has expanded by about 4 percent per annum in the Middle East countries and 5 percent per year in the North African countries excluding Egypt. That these consumption increases are largely being met from imports has already been demonstrated. By 1978 this Middle East/North African group of countries (excluding Egypt) imported close to nine million tons of wheat.

1.5 The potential for Yield Increases in SAR's -- An immediate question concerns the scope for increasing yields in such regions. Is there evidence that yield increases are attainable?

One source of evidence is from SAR's of developed countries. Table 1 shows average yield trends over recent years in South Australia, Nebraska and central Oregon, all SAR's. These data clearly show that yield increases are feasible in SAR's, even on the basis of already relatively high yields at the beginning of the period. In fact, the annual percent changes reported for Nebraska compare well with those from India. While improved varieties have played a role the dominant contributions have come from improved husbandry, leading to better moisture conservation, and to the accompanying application of fertilizers.

Table 10. Population growth rate, income and income elasticities, and per capita consumption of wheat for selected countries.

	Population Growth Rate 1970-1977 (%/year)	Income/Capita (U.S. $ 1977)	Income Elasticities for wheat[a]	Per capita Consumption Wheat[b] (kg/person)
North Africa				
Morocco	2.8	550	.4	87.5
Algeria	3.5	1,110	.6	87.8
Tunisia	2.0	860	.4	124.7
Libya	4.1	6,680	.4	84.1
Middle East				
Afghanistan	2.2	190	.4	114.8
Iran	3.0	2,160	.3	103.8
Iraq	3.4	1,550	.4	83.2
Jordan	3.3	710	.2	120.3
Syria	3.3	910	.2	125.0
Turkey	2.5	1,110	-.2	140.0
Other Producers				
Argentina	1.3	1,730	-.1	96.1
India	2.1	150	.5	28.5
Mexico	3.3	1,120	.4	20.7
Pakistan	3.1	190	.4	40.7
U. S. A.	0.8	8,520	-.3	52.5
U. S. S. R.	0.9	3,020	-.1	122.2

a/The percentage change in wheat consumption per capita for a one percent change in per capita income.
b/Estimated for 1975.

Source: World Bank (1979), and FAO (1971).

Table 11. Average farmers' yields and yield increases for selected semi-arid regions of developed countries.

South Australia	tons/ha	Nebraska	tons/ha	Central Oregon	tons/ha
1945-49	.83	1954-64	1.38	1964-66	2.03
1974-78	1.13	1966-76	2.01	1974-76	2.60
Annual rate change (%)	1.00		3.20		2.50

Source: South Australia, Australian Statistical Yearbooks; Nebraska, Barker, Gabler and Winkelmann (1978); Central Oregon, Oregon State University (1979).

Another measure of yield potential is the yield gap between yields researchers obtained in farmers' fields and those obtained by farmers. Evidence on this gap for SAR is summarized in Table 12. Results from experiments and demonstrations on farmers' fields regularly show a potential to increase yields of 50 to 100 percent even in the driest areas (see Table 12). As further evidence, a survey of national wheat programs for the Fifth Regional Wheat Program in Algiers in 1979 estimated that wheat yields in low rainfall areas were only 31 percent of potential yields.

Table 12. Comparison of farmers' yields with yields obtained from demonstration/experiments in farmers' fields in semi-arid regions.

	Farmers' yield	Yield obtained in demonstrations/ experiments in farmers' fields
	tons/ha	tons/ha
Syria - Demonstrations with durum wheat		
a. 350 + mm rainfall	1.9	3.0
b. 250-350 mm rainfall	1.2	1.9
Jordan - Demonstrations		
a. Amman Governorate 350 mm	1.2	2.0
b. Kerak Governorate 270 mm	0.9	1.5
c. Irbid Governorate 250 mm	0.8	1.3
Tunisia - Durums		
a. Inland Plateau Variety trials	0.9	2.7
b. Inland Plateau Demonstrations	0.9	2.0

Sources: Syria -- ICARDA (1978); Jordan -- Schmisseur (1976); Tunisia -- Personal communication with Country Wheat Research Program.

In summary, then, the countries of the zone from Morocco to Bangladesh include much of the wheat grown under semi-arid conditions in developing countries. Some 20 million hectares of wheat are grown in the SAR's of these countries, over one-third of their total wheat area. Demand for wheat is strong and growing, as evidenced by continuing heavy reliance on imports. While yield increases have been attained, most of this has been on irrigated and well-watered lands. There is scope for increasing yields and production in SAR's and notable advantages from doing so. The remainder of this paper is focused on some of the issues which will be confronted in pursuing those higher yields.

2.0 ECONOMICS OF IMPROVED WHEAT PRODUCTION PRACTICES AT THE FARM LEVEL.

2.1 Farmer Decision Making in Semi-Arid Environments -- We now turn to an evaluation of wheat technologies at the farm level with emphasis on semi-arid areas. This evaluation must take into account the factors that condition farmers' decision-making. These factors are presented schematically in Figure 1. The farmer is depicted as operating in a given natural and economic environment (of which he has an intimate knowledge) to allocate his scarce resources of land, labor and capital to meet certain goals.

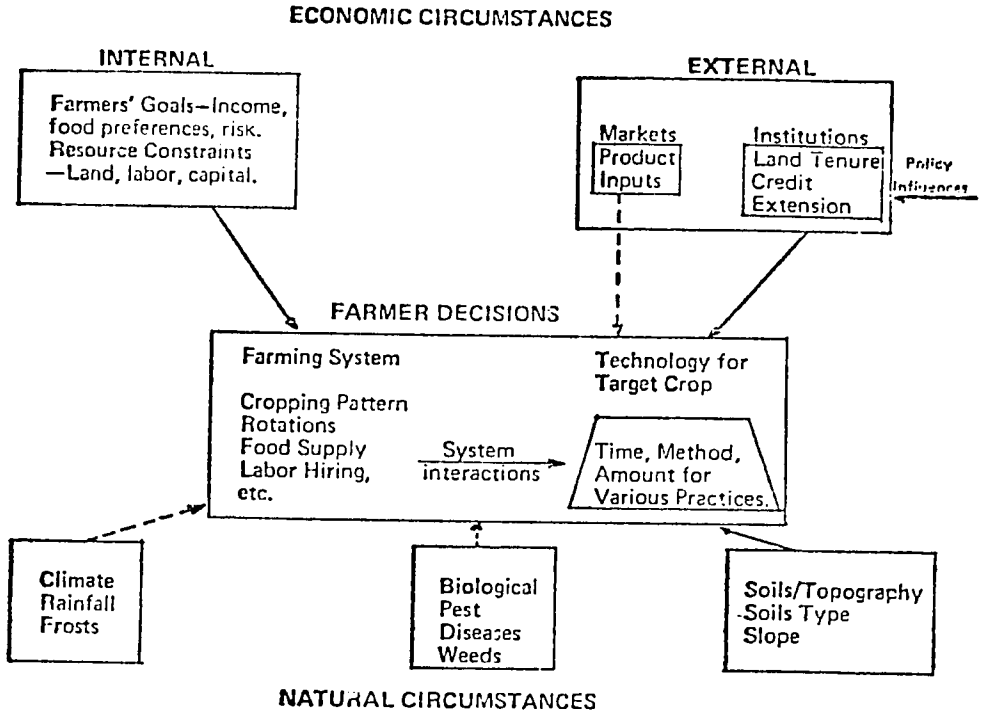
Individual farmers may have quite specific goals but three goals predominate among small farmers. First, there is now overwhelming evidence that farmers seek to increase incomes. Experience from many countries has shown that when new technologies are presented to farmers that offer opportunities for significantly increased incomes within the resources available to them, these technologies are widely adopted (Perrin and Winkelmann, 1976). Second, farmers will modify their income seeking objective to some extent, to avoid risks arising from weather or market uncertainties which may incur undue hardship to the farm business or farm family. In semi-arid areas with variable rainfall these weather risks are likely to be especially important in conditioning the environment in which farmers make decisions. For example, in the semi-arid areas of eastern Oregon, the coefficient of variation of annual wheat yields is 43 percent (Oregon State University, 1979).

Finally, small farmers, because of market risks and marketing costs, usually produce their own basic food staples. To some extent, then, preferences for different grain types and suitability for home processing will enter as a goal in small farmers' decision-making, particularly with respect to varietal choice.

Wheat production in semi-arid areas cannot be analyzed in isolation from other activities that farmers operate to meet their goals. In particular, wheat in semi-arid areas is usually produced as part of an integrated cereal-livestock system. Livestock serve various functions such as provision of a ready source of cash income and reduction of income variation in dry years. Especially important in evaluating wheat technologies is the use of the fallow cycle and crop residues for livestock.

The farmer will use improved production practices if: a) they fit the particular natural and economic circumstances of the farmer, b) adequate information is available on the new practices, and c) the necessary inputs are available to the farmer. However, rarely will a farmer adopt a "complete" package of practices, both because of the initial capital required and of the risk of the unknown in using a completely new production technique. Typically farmers will adopt new practices individually or in clusters (Manne, 1975) in a sequential manner beginning with those practices which give highest return to scarce resources when added to farmers' existing practices.

Figure 1 Various Circumstances Affecting Farmers' Choice of Crop Technology



- - - - - - ▷ Circumstances which are often major sources of uncertainty for decision-making.

In semi-arid areas, moisture is usually the overwhelming constraint. Following Bolton (1979), improved management practices in these conditions may act to a) increase the amount of water stored in the soil and reduce evaporation losses or b) use stored water and growing season rainfall more efficiently. In the short run, it is the latter type of improvement which offers the greatest potential. Moisture conservation dependent on tillage techniques usually requires additional power and appropriate implements which are not feasible in the short run to small farmers. Hence Bolton sees a sequential adoption process as follows: a) chemical weed control, b) stand establishment, c) fertilizer, d) improved varieties, e) plant population and spacing, and f) tillage and moisture conservation. Here we assemble evidence on the economics at the farm level on two of the priority factors -- chemical weed control and fertilizer use as well as briefly discuss some constraints on tillage practices in semi-arid environments.

2.2 Budgets for Evaluating the Impact of New Technologies on Farm Incomes -- Before considering the economics of improved inputs, we divert briefly to discuss some concepts important in constructing sound farm budgets for evaluating the impact of improved practices on farm income. Although the evaluation of a new technology in terms of its impact on farmers' income is not conceptually difficult, we have found that most studies substantially underestimate costs and benefits. The added costs of using a new input can be summarized as follows (Perrin *et al*, 1976):

1. Purchase price of input.
2. Cost of the transport of input to the farm.
3. Cost of labor to apply the input.
4. Cost of equipment to apply the input.
5. Cost of operating capital spent on the input.
6. Cost of harvesting, threshing and transporting extra yield produced by the input.

Typically budgets on input use ignore many of these costs, some of which are quite substantial. Transport costs for bulky inputs such as fertilizer usually add at least 10 percent to the cost of the input at the farm level. Small farmers are usually constrained by capital scarcity and the cost of capital may be quite high. We consider that an input should return at least 50 percent annually on operating capital invested to be attractive to capital-short small farmers. This rate of return is, of course, often reflected in the informal capital market where interest rates are often 50 to 100 percent or more. In the analysis below we shall assume that a rate of return of 50 percent over the production cycle is necessary to induce small farmers to rapidly adopt a new technique.[1/]

Costs of harvesting, threshing and transporting of the extra yield are usually ignored in budget calculations. Because these

[1/] For an eight-month production cycle (input purchase to product sales) this is equivalent to an annual interest charge of 75 percent.

costs vary with the level of yield, we prefer to calculate a field price of output which is the market price minus cost of harvesting, threshing and transportation. As a rule of thumb this field price is about 20 percent less than the market price for output for hand harvesting and usually somewhat less when machine harvesting is employed.[1/]

In evaluating added benefits from using an input, two factors are usually overlooked. First, caution must be used in applying yield increases obtained in experiments, even experiments on farmers' fields, to farmers who operate larger areas under different management conditions. Experiences suggest that average farmers' yields will only be 70-90 percent of experimental yields for the same technology. Second, in countries of the Middle East and North Africa, livestock is an important part of the farming system and straw and sometimes weeds are often an important component of total crop output.

2.3 Weed Control -- Losses due to weeds in wheat production in the Middle East/North African region have been estimated at 20 percent (Basler, 1979). Moreover weed competition for moisture becomes critically important in semi-arid areas leading to weed control as one of the greatest potential sources of improved water use efficiency and higher yields.

There is now ample evidence that use of herbicides to control broadleaf weeds in wheat, particularly 2-4, D is economically attractive to small farmers and is one of the first inputs widely adopted when made available to them. The cost of 2-4, D application at recommended doses is usually about 100 kg wheat as shown for various situations in Table 13.[2/] The budgets for Turkey and Tunisia have been adjusted to include costs omitted in the original sources. Also in Tunisia, where herbicides are subsidized by 50 percent, the unsubsidized prices reflects the real national cost of herbicide use. Although farmers applying herbicide for the first time may have to incur a substantial initial cost for the sprayer, in many areas a rental market for hand sprayers exists and/or herbicide is applied by contractors. In areas where weeds are extracted by hand and fed to animals, we would have other costs (value of weeds fed to animals) and benefits (saving of labor for hand weeding) of herbicide use to consider.

Evidence from on-farm experiments shows that yield increases from application of 2-4,D alone without any other changes in management are usually much higher than 100 kg/ha. In Turkey results o. 18 experiments in the dry Anatolian Plateau showed average yield increases of 280 kg/ha which even discounted by 20 percent to reflect farmers' yields would easily cover the costs (Manne, 1975). In

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[1/] Costs of machine harvesting usually do not vary greatly with yield.

[2/] These budgets do not consider the value of additional straw produced since it is assumed that total dry matter production (weeds and straw) will not change substantially with herbicide use.

Table 13. Approximate cost of application of 2-4,D herbicide to wheat in various semi-arid regions.

	Tunisia		Turkey	Mexico (High Plateau)	
	With 50% subsidy	Without subsidy	(Anatolian Plateau)	Recommended dosage	Farmers' dosage
Dosage Commercial Product	1.3 lt/ha	1.3 lt/ha	2 lt/ha	2 lt/ha	0.5 lt/ha
Product Price[a]	D 0.7/lt	D 1.4/lt	TL 161/lt	P 120/lt	P 120/lt
Application Cost[b]	D 1.25/ha	D 1.25/ha	TL 40/ha	P 130/ha	P 130/ha
Cost Herb. + Application	D 2.26/ha	D 3.1/ha	TL 162/ha	P 370/ha	P 190/ha
Cost with 50% Cost of Cap.	D 3.3/ha	D 4.6/ha	TL 243/ha	P 455/ha	P 285/ha
Market Price Wheat	D 0.62/kg	D 0.62/kg	TL 255/kg	P 3/kg	P 3/kg
Field Price Wheat	D 0.05/kg	D 0.05/kg	TL 205/kg	P 2.4/kg	P 2.4/kg
Total Cost of 2-4,D in kg wheat	66 kg	92 kg	119 kg	190 kg	110 kg

a/ Prices in local currencies: Tunisian Dinar (D), Turkish Lire (TL), and Mexico Peso (P).

b/ Calculated from the contract rate in Turkey; cost of hand sprayer plus labor for Mexico. Method of application not stated for Tunisia.

Source: Tunisia -- Republic of Tunisia, 1975; Turkey -- Manne (1976); Mexico -- Unpublished Survey Data, 1979.

Tunisia, average returns on field with average weed populations were barely enough to cover subsidized costs (Ben Zaid, 1976) but this may reflect the additional pre-sowing tillage of experimental plots (Republic of Tunisia, 1972)[1/]. Also, the economic risk of chemical weed control of broadleaf weeds is minimal since yield losses are relatively more important in drier years and there may be little interaction of absolute yield losses and moisture stress (Ben Zaid, 1976). In the dry Anatolian Plateau of Turkey, use of 2-4,D weed control was unprofitable in only one of eighteen sites (Manne, 1976).

The rapid spread of herbicide use for broadleaf weed control in semi-arid wheat producing areas in some countries in recent years is further proof of the profitability of the practice. In Turkey, the percent of wheat area treated apparently increased from 12 percent in 1975 (Manne,1975) to 50 percent in 1977/78 (Basler, 1979) in response to increased supplies of the input. In the dry altiplano of Mexico, use of 2-4,D herbicide increased from 20 percent to over 70 percent of barley farmers over a six-year period as shown in the adoption curve of Figure 2. Particularly important in this area of Mexico was the ability of farmers to adopt herbicides independently of tractor availability since most herbicides are applied by hand sprayers even on barley area up to 100 ha. Herbicides are now applied by practically all farmers in the area, many of whom have less than 10 hectares of barley.

Herbicide control of grassy weeds is considerably more expensive. For example, herbicides such as Suffix to control wild oats need to increase yields by about 350-500 kg/ha to cover all costs.[2/] Availability of these herbicides at subsidized prices in Tunisia and Algeria reduces the cost to 250-350 kg/ha (Ben Zaid, 1976 and Nelson, 1979). In Algeria, the response to Suffix application over 16 trials averaged 480 kg/ha (Nelson, 1979). In Tunisia in average fields the response was 300 kg/ha but this increased to 630 kg/ha in heavily infested fields and much higher in years with wet winters followed by a dry spring (Ben Zaid, 1976). In semi-arid areas, where yield responses are likely to be lower, the cost and risk associated with use of herbicides for grassy weeds, will prevent rapid adoption in the near future. However, with effective control of broadleaf weeds, grassy weeds will increase in importance.

2.4 Fertilizer Use -- Nitrogen fertilizer use offers potential for increased wheat yields in semi-arid areas. However, profitability of nitrogen use is strongly influenced by rainfall and unlike 2-4,D herbicide use, risk becomes a critical factor in farmers' decisions on fertilizer use.

First let us examine the profitability of nitrogen fertilizer use. As with weed control, many of the costs and benefits of fertilizer use are overlooked in analyzing fertilizer experimental data. Typically the market price of nitrogen fertilizer is divided by the

[1/] Since it is a common practice to perform extra tillage operations before planting an on-farm experiment, experimental yield response to weed control may actually be less than for farmers.

[2/] This discussion abstracts from the possibility of residual benefits from weed control over time.

market price of wheat to obtain the number of kilograms of wheat needed to pay for one kilogram of nitrogen. This is useful for international comparisons but substantially underestimates the costs faced by farmers. In fact, the crude nitrogen/wheat price ratio is at least doubled by including these costs. Budgets for nitrogen use in Turkey and Mexico are shown in Table 14 where straw yields are assumed to respond to nitrogen in the same ratio as grain. These figures show that a yield response of 4 kg and 5 kg of wheat in Turkey and Mexico respectively was necessary to pay the cost of one kg of nitrogen.

Table 14. Approximate costs of applying nitrogen fertilizer to small grains in semi-arid areas of Turkey and Mexico.

	Turkey (Anatolian Plateau)	Mexico (High Plateau)
Product	Ammonium Nitrate (26% N)	Urea (46% N)
Method of application	Machine	Broadcast
Market price of product[a]	TL 1.5/kg	P 3.2/kg
Cost of transport	n.a.	.2/kg
Field price of nitrogen (includes transport)	TL 5.8/kg	P 7.4/kg
Cost of application[b]	TL 200 per 50 kg N	P 50 per 50 kg N
Cost of fertilizer + application	TL 9.8/kg N	P 8.4/kg N
Total cost with 50 percent cost of capital	TL 14.7/kg N	P 12.6/kg N
Market price of wheat	TL 2.75/kg	P 3.0/kg
Field price of wheat (20 percent less for harvesting, threshing, transport)	TL 2.2/kg	P 2.4/kg
Field price of straw	TL 0.7/kg	P 0.1/kg
Field price of wheat + straw (price + twice price straw)	3.6	2.5
Crude price ratio (market price N/ market price wheat)	2.1	2.3
Actual price ratio (total cost N applied/ field price wheat and straw)	4.1	5.0

a/ Expressed in local currencies -- Turkish Lire (TL), Mexican Peso (P).
b/ Machine contractor for Turkey and Broadcast in Mexico.

Source: Turkey: Lynch and Tasch (1979); Mexico: Unpublished Survey Data.

One of the most comprehensive studies of nitrogen response in semi-arid wheat production was conducted by Russell (1967, 1968) in South Australia. Experiments were conducted in farmers' fields at 16 widely scattered locations with average annual rainfall from 285 mm to 500 mm. In all, data were collected for 52 site-season combinations. The average response to nitrogen was 8 kg wheat/kg N for the first 25 kg nitrogen applied, and 5 kg wheat/kg N for the second 25 kg increment in nitrogen applied, considerably below nitrogen responses typically obtained for wheat in higher rainfall areas. Economic analysis of the data was conducted by Byerlee and Anderson (1970) who derived a response function in terms of nitrogen applied, growing season rainfall and initial soil conditions. In a simplified form this function can be expressed by[1/]

$$\Delta Y = 1.372\ N - .0836\ N^2 + .03302\ NR$$

where ΔY is increased yields (kg/ha), N is nitrogen applied (kg/ha), and R is growing season rainfall (mm). Agroclimatically this region is representative of the Mediterranean areas of North Africa and Middle East, although the nitrogen response is probably somewhat lower in South Australia because of the medicago-ley fallow rotation system employed in wheat producing areas of South Australia. The data were used to construct Figure 3 which shows the combinations of nitrogen-wheat price ratios and annual rainfall at which it becomes profitable to use fertilizer.[2/] In constructing this figure we have taken into account that there is a fixed cost of fertilizer application regardless of the level applied. This fixed cost of application is assumed to be 33 kg/ha of wheat, roughly the cost of hand broadcasting in Mexico or machine application in Algeria.

The box identified by the dotted line represents the rainfall and nitrogen cost combinations commonly found in semi-arid wheat areas. To the right of the solid lines are combinations of nitrogen prices at which it is profitable to apply nitrogen. Significantly, at a low rainfall and with favorable nitrogen prices, it is profitable to apply nitrogen if fixed costs of application are low. With unfavorable nitrogen prices, rainfall must increase to at least 430 mm before nitrogen application becomes profitable. These figures then support the fact that farmers' decisions on whether to use nitrogen in semi-arid areas will be quite sensitive to the prevailing wheat/nitrogen price ratios and to average annual rainfall.

The above analysis considers only profitability and ignores risk. Most fertilizer studies show a strong positive interaction

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[1/] The initial function included interactions with initial soil nitrate and initial soil moisture. The present function has been derived by settling initial soil moisture to 6 percent and soil nitrate to 3 ppm.

[2/] In constructing Figure 3, we have assumed that total cost of nitrogen use (cost of capital, application costs, etc.) are double market prices for nitrogen (see Table 14). Moreover, the response function was estimated in terms of growing season rainfall (May to October) which we estimate to be, on average, 70 percent of annual rainfall in South Australia conditions.

between rainfall and nitrogen response. In the extensive South Australia studies presented above, nitrogen response in dry years was negligible and in some years and sites with a hot spring, grain yields were depressed by nitrogen application (Russell, 1968).[1/] Nitrogen use in semi-arid wheat production is then a risky investment.

The effect of risk on nitrogen use depends on the amount of risk, and the farmer's attitude toward risk. The first of these can be measured by variance or standard deviation of profits or by the probability that profits will fall below zero. Using the latter criteria we have used the South Australian data presented above to calculate in Table 15 the probability that farmers would lose money due to rainfall variation by applying the profit-maximizing levels of fertilizer presented in Figure 3b. For low nitrogen prices, nitrogen use in low rainfall areas (less than 300 mm) would not be profitable in one year in three but falls to one year out of seven at higher rainfall. With higher prices for nitrogen, the probability of not making profits rises to one year in three even in the higher rainfall areas. However, farmers are more likely to be concerned about risk of not recovering cash costs of nitrogen purchases, in which case the probabilities of losing money fall to less than one year in five in all cases.

Table 15. Probability of losing money from nitrogen application on wheat, South Australia.

Total cost of nitrogen use (kg wheat/kg N)	Annual rainfall (mm/year)	Optimal level of nitrogen (kg/ha)	Probability that profits less than [a/]	
			Total cost nitrogen use	Cash cost of nitrogen use[b/]
4	285	24	.34	.16
4	425	44	.18	.10
4	500	53	.15	.08
8	285	0	[c/]	[c/]
8	425	20	.46	.18
8	500	30	.34	.13

[a/] Calculated from response function of nitrogen and rainfall, assuming normal distribution of rainfall, coefficient of variation of growing season rainfall of 0.33 and fixed cost of application of 25 kg wheat.

[b/] Includes only cash cost of nitrogen purchase excluding cost of capital.

[c/] Not profitable to apply nitrogen.

[1/] However, straw yields were not adversely affected, which lessens risk in areas where straw has a high economic value as forage.

Whether these levels of risk affect the decision to use nitrogen and the level of nitrogen used, depends on the decision makers' risk preferences. Most studies indicate that farmers will accept lower profits if risk is thereby reduced and will therefore use lower input levels if this reduces risk. In the South Australia example, we used the theory of decision making under risk (Anderson et al., 1977) to predict that farmers with average risk aversion would use about 25 percent less nitrogen than a profit maximizing farmer in lower rainfall areas.[1/] Moreover, as shown in Figure 3a, the set of rainfall and nitrogen wheat price ratios in which farmers would use nitrogen is reduced substantially and risk averse farmers in the lowest rainfall areas would no longer apply nitrogen fertilizer, even at the more favorable prices for nitrogen.

Results from scattered fertilizer experiments elsewhere also indicate the substantial risk in applying nitrogen to wheat. In the last ten years of fertilizer experiments on dryland wheat in Jordan, reported in Duwayri and Saket (1978), less than half seem to show an economic response to nitrogen. Data from areas of Tunisia with less than 500 mm annual rainfall and total cost of nitrogen equivalent to 5 kg wheat indicate, on average, an economic response to nitrogen up to 66 kg/ha. However, in two out of the five years, represented in the data, farmers would be better off by applying only 44 kg/ha of nitrogen.

To some extent, farmers can avoid risks by splitting nitrogen application with perhaps half the dose applied at planting and the second application applied depending on stand establishment and available soil moisture. Also, phosphorous application is considerably less risky since it may give a response even in dry years (Russell, 1968) and residual phosphorous can be carried over to the next season.

In summary, fertilizer use and particularly nitrogen use, given current farmer prices for fertilizer seems to be profitable even in the lowest rainfall wheat areas, although risk may be a severe deterrent to nitrogen use in these areas. Moreover, fertilizer can be broadcast by hand independently of machine availability and is therefore particularly appropriate to small farmers. While fertilizer use has increased rapidly in some SAR's (e.g. the Anatolian Plateau of Turkey), average rates of use of both nitrogen and phosphorous are usually below 10 kg nutrients per hectare in the countries of the SAR's (FAO, 1976).

[1/] Given farmers will trade off profits for risk, it can be shown that the optimal level of an input x is given by the solution of the equation, $r = \frac{dy}{dx} - MRS\ d(y)/dx$ where ri is the cost of nitrogen (in kg wheat), dy/dx is the marginal physical product of input, x, (y) is the standard deviation of yield and MRS the decision makers' rate of substitution between profits and risk -- i.e. high value for MRS indicates greater risk aversion (Anderson et al., 1977). Several studies (e.g. Dillon and Scandizzo, 1978) have shown that many farmers in LDC's have a value of MRS of about 0.5, the value we used in these calculations.

2.5 Tillage Practices -- Tillage practices are important in moisture conservation, weed control, and stand establishment. Extensive experimentation in the Anatolian Plateau of Turkey has demonstrated a substantial yield advantage of over 500 kg/ha from early tillage followed by a clean fallow to conserve summer moisture. However, the use of weedy fallow for livestock and the high price of forage resulted in only 27 percent of farmers adopting this practice in 1975/76 compared to 58 percent who were using herbicides (Manne, 1977). The partial budget in Table 16 shows that when forage value of weed and straw is taken into account, the benefits of early tillage are negligible. Moreover, the farmer who practices early tillage must wait over a year to reap the benefits of early tillage while the benefits from weeds are realized in a far shorter time. This is an additional disincentive to farmers with scarce capital.

A second difficulty with improved tillage operations in the short run is the need for additional power to be available in a timely fashion. A recent survey in the semi-arid barley area of Mexico's high plateau shows substantial differences in tillage practices among owners and renters of tractors. As shown in Table 17 tractor owners plough earlier, harrow more frequently and plant earlier than tractor renters. To some extent the later ploughing of tractor renters reflects the fact that many small farmers (who are largely tractor renters) graze straw residues while large farmers bale straw to sell. But even allowing for this difference, tractor renters have difficulty obtaining tractor services in the short time when moisture is suitable for either primary or secondary tillage and on average there was a 12-day lag from the time services were requested until delivered. However, there is evidence that with increasing number of tractors in the area (and virtual disappearance of animal power) the timing and intensity of tillage operations among tractor renters is improving.

Table 16. Added benefits and costs of early tillage.a/

Added Benefits		
Added yield in experiments		0.60 tons/ha
Added yield in farmers' fields (90% experimental yield)		0.54 tons/ha
Added straw yield (twice grain yield		1.08 tons/ha
Market price of wheat	TL	2.75/kg
Field price of wheat (less 20 percent for harvest costs)	TL	2.20/kg
Field price of straw	TL	.90/kg
Total added benefits	TL	2160.00/ha
Added Costs		
Weed yield foregone (dry matter)		2.00 tons/ha
Price for weeds (approximate)	TL	2.10/kg
Foregone value of weeds	TL	2000.00/ha
Extra cultivation to clean fallow	TL	150.00/ha
Total added costs	TL	2150.00/ha

a/Monetary units are Turkish Lire (TL)

Source: Lynch and Tasch (1979)

Table 17. Comparison of tillage practices of farmers who rent tractors and who own tractors in the Central Valley, Mexico.

	Tractor renters	Tractor owners
Percent plough immediately after harvest	18	33
Percent plough on intermittent dry season rainfall	41	57
Percent plough after beginning of rainy season	41	11
Average number of pre-planting cultivations	1.4	1.8
Percent plant with beginning of rains	30	40

Source: Unpublished Survey Data.

2.6 Farmers' Adoption of Improved Production Packages -- We hypothesized at the beginning of this section that in SAR's farmers would generally follow an adoption sequence initially emphasizing divisible inputs -- chemical weed control followed by fertilizer use -- accompanied by gradual improvement of practices such as tillage methods which are dependent on increased availability of power and machinery, and by improved varieties.

In fact, evidence from semi-arid areas in which rapid technological change has taken place support this type of adoption sequence. Table 18 shows that for the Turkish Anatolian Plateau in 1975/76 the rates of adoption were highest for seed treatment, followed in descending order by drilling and phosphorous use, herbicide application, spring nitrogen application, early plowing and additional tillage and high-yielding varieties. It is likely that the number of herbicide users would have been higher had there not been a shortage of herbicides. The cross-tabulation of practices used shows where important interactions occur. It is significant that nearly all farmers who used nitrogen fertilizer also applied herbicide but only 20 percent of nitrogen users were growing high-yielding varieties.

Similar findings in the semi-arid upper plateau of Mexico for barley are shown for the adoption of 2-4,D herbicide use, fertilizer (mo[illegible] nitrogen), and planting with a grain drill (Figure 2). Use of 2-4,D rose very rapidly from 1968-1975 closely followed by nitrogen fertilizer use. Adoption of grain drilling has been much more gradual and was only used by 40 percent of farmers in 1979.

Cases of non-adoption of practices are usually associated with unprofitability, risk or lack of availability of relevant inputs.

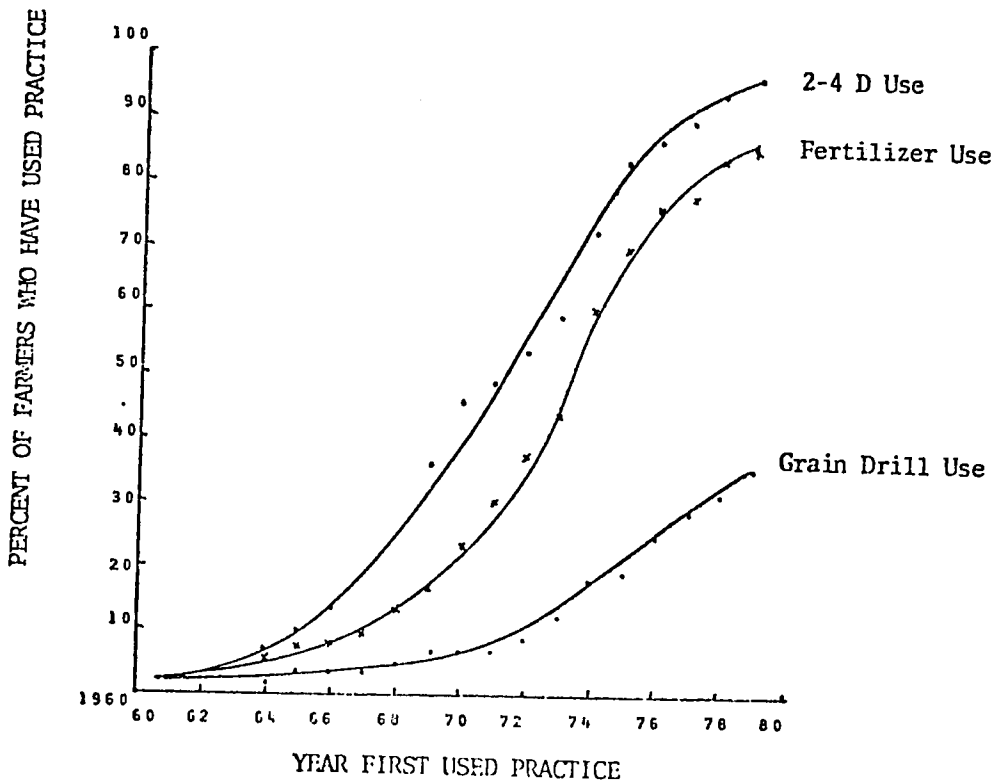

Figure 2. Adoption for Various Barley Production Practices, Central Plateau, Mexico.

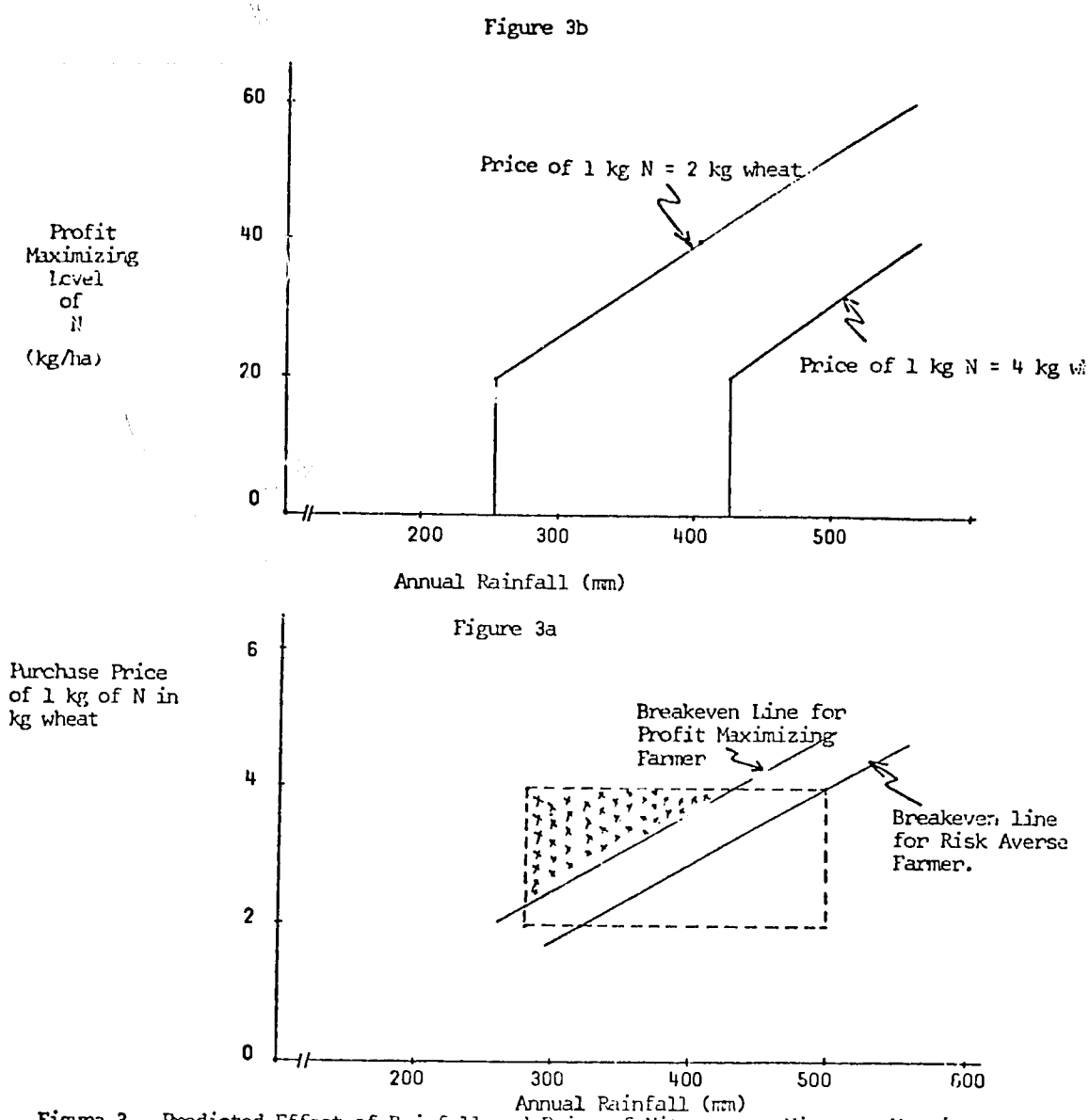

Figure 3. Predicted Effect of Rainfall and Price of Nitrogen on Nitrogen Use in South Australia. Figure 3a. The solid lines are breakeven lines for profit-maximizing and risk averse farmers. That is for combinations of price of Nitrogen and rainfall to the right of these lines farmers would use Nitrogen. The box shown by the dotted line shows relevant combinations of prices and rainfall for SAR's. Figure 3b. Shows the optimal level of N for varying rainfall for two prices of Nitrogen. Farmers need to apply about 20 kg of nitrogen to cover a fixed cost of application of 33 kg wheat.

After an extensive demonstration program in semi-arid wheat areas of Jordan (250-400 mm rainfall) adoption of the 'package' was low. The package consisting of four operations for land preparation to provide clean fallow, drilling, nitrogen and phosphorous application and 2-4,D use raised yields by an average of 650 kg/ha or 50-70 percent over farmer practices (Schmisseur, 1976). However, even with favorable assumptions of 10 percent harvesting costs, 25 percent return on capital and no forage value of weedy fallow, the yield increase required to cover costs is close to 700 kg/ha[1/] and this was only achieved in 6 of 23 villages in 5 seasons in which the demonstrations were made. However, in somewhat better rainfall areas 2-4,D use combined with nitrogen and phosphorous application was profitable in almost all cases[2/] (Gotsch, 1976). This experience shows the need to disaggregate "technological packages" and this will usually require extensive agronomic research prior to reaching the demonstration stage. This is discussed in the next section.

3.0 RESEARCH AND POLICY ISSUES

Increased wheat production in semi-arid areas will come about through applied research to develop technologies appropriate to farmers in the area, combined with availability of inputs and price incentives to implement these technologies. In this section we offer some evidence and recommendations for each of them.

3.1 Agricultural Research -- We have already emphasized the importance of management relative to variety in increasing wheat yields in semi-arid regions. While we have made some generalizations about the type of technologies and sequences of adoption of technologies in semi-arid areas, we stress that much research is needed to adapt these technologies to the specific climatic, soils and economic circumstances of each semi-arid area.

Our review of agronomic research in the SAR of Middle-East/North Africa area indicates that, with few exceptions such as Turkey, there has been very little agronomic research and particularly agronomic research aimed at representative farmers. Much of the agronomic research has been conducted on experimental stations which usually do not represent conditions in farmers' fields, and even where research has been conducted in farmers' fields we have the impression that it is not aimed at representative farmers -- often the small resource-poor farmer. For example, in both Tunisia and Algeria, extensive fertilizer trials were conducted in farmers' fields in the early 1970's. In the dry upper plateaus of Algeria the average yield in the check plot without fertilizer over five years of trials was over 2 tons per hectare (FAO, 1976)[3/] in a

1/ These results are somewhat more negative than found by Schmisseur (1976) because we have used a higher cost of capital and included harvesting costs. The forage value of weedy fallow was not considered by Schmisseur.

2/ These demonstrations were conducted under improved land preparation so the response to fertilizer use may be somewhat higher than farmers would obtain.

3/ See for example Winkelmann and Moscardi (1979) and CIMMYT Wheat Training (1979).

region where farmers' average yields are 0.5 tons/ha or less. In this case, fertilizer trials were conducted only in the socialist sector and we assume under optimal agronomic conditions. In Tunisia, yields in five years of trials on sites with less than 500 mm average rainfall were 2.8 tons per hectare in unfertilized plots, again indicating either non-representative fields or underlying agronomic practices very different to what farmers are likely to use in the foreseeable future.

In addition, there is also a shortage of farm-level economic studies in the region to provide a knowledge and understanding of farmers' existing system. As a result, there is a serious lack of information on such questions as constraints on improved tillage operations, operation of tractor hire schemes, crop-livestock interactions, farmers' cash flows in relation to needed inputs and farmers' perception of risk and the influence of risk on the choice of management practices.

We believe an important means of increasing the relevance of research to farmers is through programs of area specific on-farm research. We have elsewhere described procedures developed by CIMMYT for conducting such research and only summarize its main elements here.[1/] As shown in Figure 4, on-farm research emphasizes collaboration of agronomists and economists to identify and understand the circumstances of farmers through farm surveys and/or informal interviews with farmers who are the target of the research. This helps to more clearly focus experiments in farmers' fields by identifying key constraints to increased production, as well as those technologies for overcoming these constraints which best fit farmers' goals and resources. Although on-farm research usually has as an immediate objective the formulation of recommendations appropriate to farmers, we are increasingly finding that the process of working in farmers' fields in communication with farmers provides valuable guidance to experiment station research and to policy formulation.

Implementation of effective on-farm research programs in the region will require greater resources for agronomic research and involvement of economists in the early stages of research design. This implies some restructuring of agricultural research institutes (many do not currently employ economists), and appropriate incentives to ensure the implementation of such farmer-oriented research.

Finally, it might be argued that payoffs to scarce research resources may be higher if invested in higher rainfall areas than semi-arid areas. To some extent this is true. Yields in better rainfall coastal areas of Turkey increased by 4-7 percent from 1961-76 compared to 2-3 percent in the semi-arid central plateaus. In Algeria the experimentation/farmer yield gap in 1979 in drier

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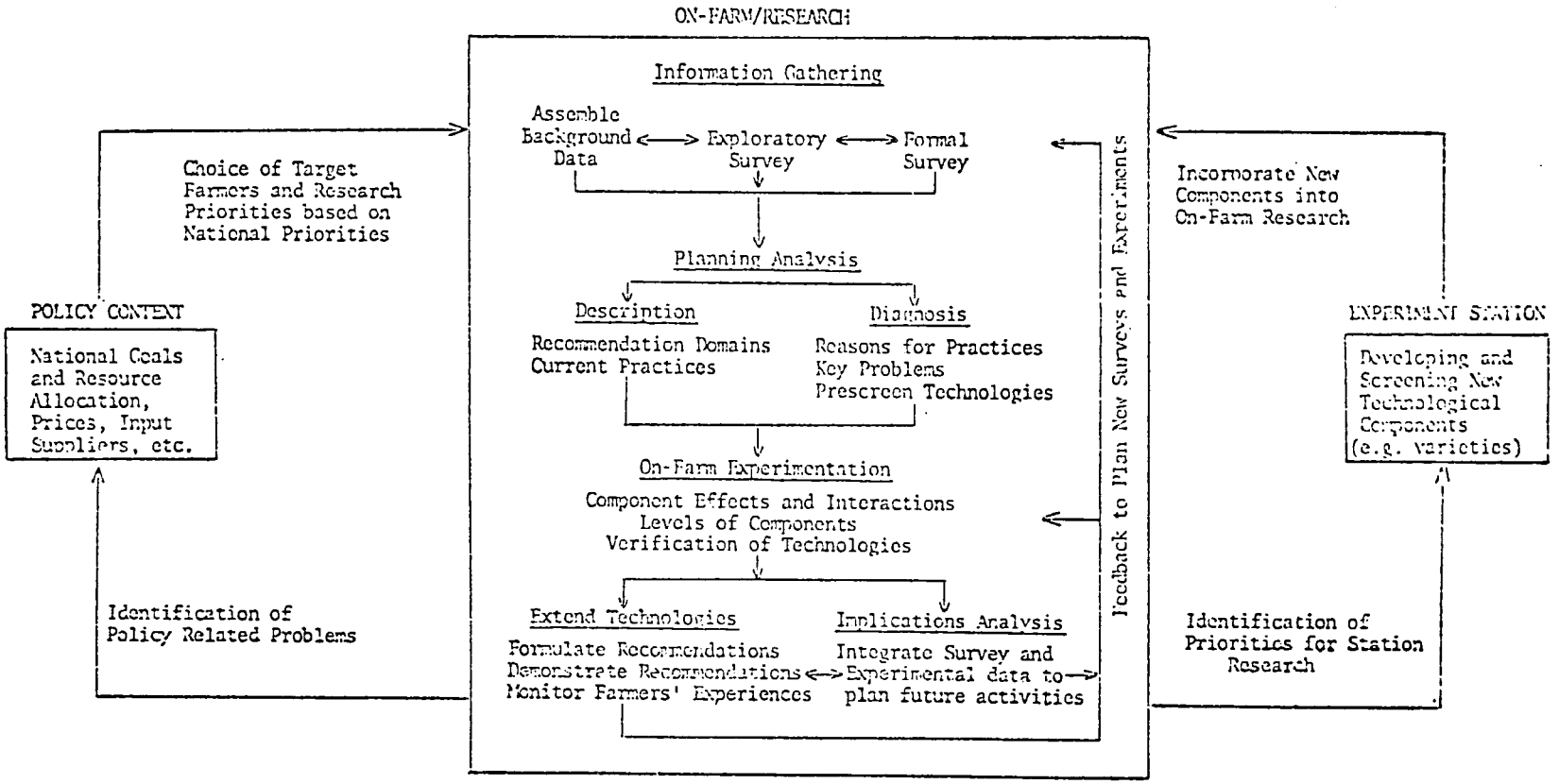
[1/] See for example Winkelmann and Moscardi (1979) and CIMMYT Wheat Training (1979).

FIGURE 4 OVERVIEW OF AN INTEGRATED RESEARCH PROGRAM



areas was a little over one ton/ha compared to a gap of over 2 tons/ha in higher rainfall areas. However, the very size of the semi-arid wheat area and the number of people dependent on wheat in these areas is alone justification for research aimed at these areas. Moreover in many cases it may be possible to allocate research resources so that there are spinoffs to semi-arid areas. For example, we have the impression that much wheat research in North Africa has emphasized the high rainfall coastal areas and research findings have little or no relevance to semi-arid areas. A research strategy focused on the intermediate rainfall areas further inland may have high payoffs to these areas as well as significant spinoffs for the semi-arid areas.

3.2 Price Incentives for Wheat Production in Semi-arid Areas -- Reliable data on producer prices for wheat and associated inputs are difficult to find. From several sources (including our own observations) we have assembled in Table 19 some producer prices which seem to be consistent across various sources. Prices of wheat are quite variable by country. Assuming that on average over the last five years, it has cost from US $150-200 a ton to land imported wheat in North Africa/Middle East, domestic wheat prices are somewhat lower than world prices in some countries such as Tunisia and much higher in others such as Algeria.

Relative prices are more useful in comparing incentives for wheat production. On the one hand input-output price ratios are indicative of incentives for more intensive management. In Table 19 we show price ratios of nitrogen fertilizer to wheat. Significantly for most Middle East/North Africa countries, price incentives for nitrogen use are quite strong relative to irrigated wheat areas such as India and Pakistan, and especially strong when compared to large wheat producers such as Australia and the U. S. A.

The cost of nitrogen in terms of wheat is kept low relative by high support prices for wheat (e.g. Algeria) and/or government subsidies on fertilizer prices. Subsidies in 1976/77 for nitrogen fertilizers were 40-50 percent of farmgate prices in Iran, Syria and Turkey in 1976 and 20 percent of farmgate prices in Tunisia (FAO, 1978). Subsidies on fertilizer can be justified for various reasons. Purely on economic efficiency criterion, subsidies may be used to induce farmers facing risks and capital scarcity to use fertilizer at levels nearer to socially optimum levels than they could otherwise use. For example, using the nitrogen response curve of section 2.4, a subsidy of 50 percent would be needed to induce farmers to use fertilizer at a socially optimum level that maximizes profits (regardless of risks) at a social cost of capital of 20 percent. Moreover, a subsidy program is usually more efficient and easier to administer than a credit program to overcome capital scarcity or a crop insurance program to counter risks.

The second set of price relations affecting wheat production is the relationship between the price of wheat and competing farm activities. In the semi-arid areas, the main competing activity is livestock, especially sheep. Evidence on meat/wheat price ratios

Table 18. Adoption of selected practices in wheat production in Ankara Province, Turkey, 1975-76.

	Practice					
	Treated seed	Herbicide	Drilling (and phosphorus use)	Plough early	Nitrogen	High yielding variety
	Percent farmers who use practices					
All farmers	92	58	70	27	43	12
Farmers applying nitrogen	97	84	71	37	100	20
Farmers ploughing early	100	65	93	100	60	24
Farmers using HYV	100	84	100	56	68	100

Source: Manne (1977)

Table 19. Approximate prices received by farmers for wheat and paid by farmers for nitrogen fertilizer by country.

Country	Year	Price of wheat $US/ton	Price of nitrogen $US/ton N	Ratio price of wheat to nitrogen
Middle East/North Africa				
Algeria	1980	345	345	1.0
Tunisia	1977	135	350	2.6
Jordan	1979	330	465	1.4
Syria	1977	182	496	2.7
Turkey	1979	125	270	2.2
Afghanistan	1978	130	420	3.2
Iran	1978	200	300	1.5
Other Countries				
India	1979	154	400	2.6
Pakistan	1979	114	333	2.9
Australia	1977	84	357	4.2
U. S. A.	1980	127	406	3.2

Sources: Assembled from USDA (1979), FAO (1978), Schaefer-Kehnert (1978) and our own personal interviews with farmers in various countries.

is very scanty but very approximately we have estimated that at the farm level a sheep is valued at about 1000 kg of wheat in Tunisia, 500 kg of wheat in Algeria, and about 200 kg of wheat in South Australia. That is, in countries of the Middle East and North Africa the price of mutton relative to wheat is at least twice as high as in Australia. Partly because of oil and gas production, the North Africa/Middle East is on the whole a region of rapidly rising per capita incomes. It is also a region of high population growth rates relative to other regions at comparable stages of development. Increasing incomes and population are likely to increase the price of meat relative to wheat. A recent Oregon State University report estimates that the demand for meat is growing at 8 percent per annum because of a high propensity to increase meat consumption with rising income. At the same time meat production is rising at only 3 percent per annum leading to upward pressure on meat prices. Of course wheat demand is also outstripping supply, but, as we have seen, this is being met by large increases in wheat imports. On the other hand, transportation and handling costs for meat imports are much higher. Even so, meat imports to North Africa and the Middle East have increased in recent years, particularly from Australia and New Zealand. These crop-livestock interactions add considerable complexity to policy decisions on increased wheat production that demand a thorough analysis of alternative strategies of domestic forage production, medic-ley farming and imports of feed grains and meat to relieve pressure on meat prices.

3.3 Input Availability — In addition to price incentives, reliable and accessible product and input markets are needed to induce increased wheat production. Our impression is that reliable product markets are usually less of a problem for wheat than input distribution. This impression is reinforced by contrasting the experience of Algeria with that of Tunisia. Price policies apparently are more favorable to Algerian wheat -- e.g. nitrogen costs in Tunisia are roughly 2.5 kg wheat and in Algeria 1.0 kg wheat while the wheat cost of sheep is lower in Algeria than in Tunisia. Even so, the annual change in yield in Tunisia is notably larger than for Algeria.

The problem with input distribution varies. Fertilizer often suffers from a limited number of distribution points, particularly if distribution is handled by the public sector. For the small farmer, the transport costs of bringing the fertilizer to the farm may be a severe deterrent to fertilizer use. Herbicide, on the other hand, is not a very bulky item. However sprayers -- either tractor or backpack -- as well as the herbicide must be available for herbicide application.

Availability of machinery to small farmers depends on the establishment of a rental market. In Turkey and the upper plateau of Mexico this has largely been established by the private sector -- usually medium to larger farmers who rent machinery to small farmers

after completion of work on their own farms. In both cases the levels of mechanization even on small farms has risen very rapidly. For example, the number of tractors in operation in Turkey more than doubled from 1968-1976. Research too can help rationalize machinery import policy. For example, in Algeria, Nelson (1978) has shown that heavier combination drill-cultivators from Australia give substantially superior results to the conventional European models.

4.0 CONCLUSIONS

From Morocco to Bangladesh, wheat production under semi-arid conditions accounts for a significant proportion of wheat sown. Yield in these areas is low and most of those countries with large semi-arid areas generally have yield increases well below population growth. Moreover, with expanding population and income, demand for wheat, the staple food cereal, is increasing at 4 to 5 percent per annum, a large part of which is being met by imports. For the Middle East and North Africa (excluding Turkey, a wheat exporter and Egypt with irrigated wheat) wheat imports have risen to 9 million tons by 1978 or from 14 in 1963 to 31 percent in 1978 of total consumption. However, experience of yield increases in SAR's of developed countries, and some SAR's of developing countries such as Turkey, along with research results show the potential for increasing yields by 50 to 100 percent or more in most SAR's.

There is ample evidence that farmers in SAR's will rapidly adopt improved technologies that fit their particular natural circumstances (soils and climate) and economic circumstances (goals of increased income and risk aversion, and resource availability). There are relatively few farm-level economic studies on wheat technologies in SAR's and most ignore important costs and benefits as well as the crop-livestock interactions that influence farmers' decisions. Nonetheless we have shown that some technologies such as broadleaf weed control and fertilizer use are often appropriate to farmers -- particularly resource-poor farmers in SAR's, since they can be applied independently of tractor availability by hand methods. Some inputs, such as nitrogen, are somewhat more risky, but even these inputs seem to be appropriate except perhaps in the lowest rainfall areas. Improved land preparation and moisture conservation also show promise of increased yields but improvement is usually slower because of the need for increased power and machinery and the competition with weedy fallow use by livestock.

Increased farm-level agronomic and economic research is needed to establish improved practices appropriate to farmers in each SAR. This requires additional resources for on-farm research, early involvement of applied economists in this research and appropriate incentives to orient research to farmers.

At the policy level, it seems that price incentives to use improved management practices are usually provided at least in terms

of input/output price ratios. However, expanded wheat area or use of practices such as early tillage which compete with livestock are constrained by policies which keep wheat prices low relative to livestock. Obviously, price incentives for input use have little effect unless inputs are made available to a wide number of distribution points in a timely way. It is in the area of management of input acquisition and distribution that policy can play the largest role in improving wheat production in SAR's in the near future.

References

Anderson, J. R., J. L. Dillon and J. B. Hardaker. 1977. Agricultural Decision Analysis. Iowa State University Press, Ames, Iowa.

Basler, F. 1979. Chemical weed control as an integrated part in Cereal Production. ICARDA.

Ben Zaid, A. S. 1975. A model of economic analysis for the use of herbicides. Third Regional Wheat Workshop, Tunisia.

Bolton, F. E. V. 1979. Agronomic yield constraints in rainfed cereal production systems. Fifth Regional Cereals Workshop, Algeria.

Byerlee, D. R. and J. R. Anderson. 1969. Value of predictions of uncontrolled factors in response analysis. Australian Journal of Agricultural Economics 18(2):118-127.

CIMMYT Economics Program. 1979. Planning technologies appropriate to farmers: concepts and procedures. CIMMYT, Mexico.

Dalrymple, D. G. 1975. Evaluating fertilizer subsidies in developing countries. AID.

Duwayri, M. and I. Saket. 1978. Response of wheat to fertilizers in Jordan: twenty-five years of experiments.

Gotsch, C. H. 1976. Wheat price policy and the demand for improved technology in Jordan's rainfed agriculture.

ICARDA. 1978. Farmers field verification trials in the Syrian Arab Republic 1977-1978. Project Report No. 1.

Lynch, J. A. and E. B. Tasch. 1979. Early tillage in Turkey's Anatolian Plateau. SEARCA/CIMMYT Agricultural Production Management Seminar, Philippines.

Mann, C. K. 1977. The impact of technology on wheat production in Turkey.

Mann, C. K. 1977. Factors affecting farmers' adoption of new production technology: clusters of practices. Fourth Winter Cereals Workshop-Barley, Jordan.

Nelson, W. 1978. Management for increased wheat production in Algeria.

Oregon State University. 1979. Dryland agriculture in winter precipitation regions of the world.

Perrin, R. K. and D. L. Winkelmann. 1976. Impediments to technical progress on small versus large farms. AJAE 888-894.

Perrin, R. K. et al. 1976. From agronomic data to farmer recommendations. CIMMYT, Mexico.

Russel, J. S. 1967. Nitrogen fertilizer and wheat in a semi-arid environment: effect on yield. Australian Journal of Experimental Agriculture and Animal Husbandry 7:453-461.

Russel, J. S. 1967. Climatic factors affecting response. Australian Journal of Experimental Agriculture and Animal Husbandry 7:453-461.

Schaefer-Kehnert, W. 1976. The use of price ratios as choice indicators. World Bank.

Scandizzo, P. L. and J. L. Dillon. Peasant agriculture and risk preferences in North East Brazil: a statistical sampling approach. In Roumasset, J. A., et al. (1978) Risk Uncertainty and Agricultural Development. SEARCA/ADC. Philippines.

Schmisseur, W. E. 1976. Economic evaluation of dryland wheat technologies, introduced in Jordan.

(Republic of) Tunisia. Projet de Ble, 1975.

Winkelmann, D. L. and E. Moscardi. 1979. Aiming agricultural research at the needs of farmers. CIMMYT, Mexico.

THE EFFECT OF DROUGHT STRESS ON THE YIELD OF DURUM WHEAT CULTIVARS

G. Gebeyehou and D. R. Knott
Canada

Abstract

A range of durum wheat cultivars was tested for the effects of drought stress under both greenhouse and field conditions. Controlled moisture levels were used in the greenhouse, and irrigated and non-irrigated conditions in the field.

In the greenhouse, the reduction of yield due to moisture stress was closely correlated with the yield of the cultivars under non-stress conditions. The high-yielding cultivars showed the greatest loss, almost all of which was due to reduction in the kernel weight. Field tests were run in 1976 and 1977. Drought stress was relatively low in 1976 and severe in 1977. In neither year did the cultivars differ significantly in their response to drought stress.

Introduction

Drought tolerance is of great importance in many crops. It is relatively difficult to measure drought tolerance other than by extended tests at different locations and years. Despite the extensive work that has been done in cereal crops, it has not been possible to clearly relate drought tolerance to specific morphological or physiological characters.

Durum wheat is commonly grown in areas where drought stress frequently occurs and the species probably has considerable drought tolerance. Some cultivars are reputed to be more tolerant than others. In Canada, Pelissier has the reputation of being drought tolerant. Hurd (1964) showed that Pelissier had a very extensive root system and that a rather small portion of the root system occurs in the top three inches of soil which are often dry.

Relatively little work seems to have been done to compare the relative reduction in yield and other characters caused by drought stress in durum wheat. In the present study, both greenhouse and field tests were used to measure the relative response of a series of durum cultivars to drought stress and to see if the results might provide an indication of the basis for drought tolerance. A total of 12 durum cultivars of fairly diverse originals but all reasonably well adapted to Saskatchewan conditions were studied (Table 1).

Crop Science Department, University of Saskatchewan

Table 1. Durum cultivars used in the experiments.

Cultivar	Origin	Cultivar	Origin
Anhinga	Mexico	Pelissier	Algeria
Botno	U.S.A.	Qualifen	Chile
Hercules	Canada	Stewart 63	Canada
Kubanka	Russia	Wakooma	Canada
Leeds	U.S.A.	Ward	U.S.A.
Macoun	Canada	Wascana	Canada

Greenhouse Tests

In the greenhouse studies, six cultivars were grown in large sheet metal tubes 32 cm in diameter and 91 cm deep. Five plants were grown in each container. Two water regimes were used, (1) regular watering as needed, (2) regular watering until five days after anthesis and then no further watering. It was hoped that, by using deep containers, drought stress would develop slowly as it does in the field. The experiment was run in 1976 and 1977 with two replicates each time.

The cultivars differed significantly in their response to drought stress in 1976 but not in 1977 (Table 2). However, the loss in yield was closely correlated with the yield under non-stress conditions (r = 0.938** in 1976 and 0.823* in 1977). The range in yield was large in both years: 34.8-95.4 g per container in 1976 and 39.7-69.2 g per container in 1977. The low yielding cultivars showed lower reductions in yield under stress, but it seems unlikely that this reflects tolerance to drought. More probably, under stress conditions the more vigorous, high yielding cultivars used up the available moisture more quickly and then suffered severely.

Table 2. Reduction in yields caused by drought stress under greenhouse conditions.

Cultivar	Reduction in yield in % (Non-stress--stress/Non-stress) 1976	1977
Stewart 63	68.2	58.5
Pelissier	57.9	48.7
Wakooma	50.8	36.4
Kubanka	44.6	45.9
Anhinga	5.6	35.8
Botno	20.4	15.9
Bayesian LSD	31.9	N.S.

Since stress did not develop until after anthesis, the main effect was on weight per 1000 kernels. The reduction in weight per 1000 kernels was closely correlated with the reduction in yield (r = 0.929** in 1976 and 0.946** in 1977).

Of the three yield components, the cultivars differed most in the number of heads per container, although there were significant differences also in number of kernels per head and weight per 1000 kernels. Under non-stress conditions the number of heads per container correlated closely with yield (r = 0.973** in 1976 and 0.919** in 1977).

Field Experiments

Nine durum cultivars were tested in adjacent, duplicate irrigated and rainfed tests in 1976 and all 12 cultivars were tested in 1977. In 1976, all the cultivars were planted at three different seeding dates. Plots of each cultivar that headed at about the same date were selected for analysis. In this way drought stress occurred at about the same stage of development for each cultivar. In 1977, the late cultivars were seeded 10 days earlier than the early cultivars with the same objective in mind. All cultivars headed within four days. Plots were 4 rows, 3.66 m long and there were 6 replicates in 1976 and 5 replicates in 1977. In 1976, two rows were harvested, while in 1977 all four were harvested.

In 1976, rainfall was above normal in June and July and drought stress in the rainfed plots reduced yield by only 16.2%. In 1977, May had above normal rainfall, but June, July, and August were all very dry, resulting in severe drought stress. Rainfed plots yielded 58.9% less than the irrigated plots. The yields from irrigated plots were similar in both years.

The cultivars differed significantly in yield in all four tests. However, the differences were much smaller than in the greenhouse tests. In both years the interaction between cultivars and moisture conditions was not significant. Thus, the cultivars did not respond differently to moisture stress (Table 3). It is interesting to note, however, that Pelissier, which has a reputation for drought tolerance, gave the lowest reductions in yield in both years.

In 1976, drought stress caused small but significant reductions in all three yield components, with the greatest reduction in weight per 1000 kernels (Table 4). Because drought developed much earlier and stress was more severe in 1977, the reductions were much greater except in weight per 1000 kernels. There were significant reductions in all three yield components with the largest being in number of heads per plot (40.3%) and the smallest in weight per 1000 kernels (6.9%).

Table 3. Reduction in yields caused by drought stress in the field experiments.

Cultivar	Reduction in yield in % (Irrigated--rainfed/Irrigated) 1976	1977
Botno	--	65.2
Lees	14.0	61.9
Anhinga	--	61.6
Qualifen	19.6	61.6
Ward	16.5	61.5
Hercules	15.7	60.6
Wascana	13.3	60.4
Kubanka	--	59.4
Macoun	23.6	58.6
Wakooma	13.8	55.8
Stewart 63	19.6	51.7
Pelissier	10.0	47.8
MEAN	16.2	58.9

Table 4. Reduction in yield components caused by drought stress in the field experiments.

Component	Reduction from drought in 1976	1977
Heads per plot	4.1%*	40.3%*
Kernels per head	4.6 *	30.4 *
Weight per 1000 k.	7.9 *	6.9 *

* Significant at the 0.05 level of probability.

In both years there was a significant interaction between cultivars and moisture conditions for the yield components. However, the results for individual cultivars were not consistent from component to component or from year to year. Thus, no cultivar gave consistently low reductions in yield and yield components as a result of stress. In 1977, when drought stress was severe, Wakooma, Stewart 63 and Pelissier did show below average reductions in number of heads per plot and number of kernels per head. These were the two components most affected by drought.

Discussion

The greenhouse and field experiments gave somewhat different results. Nevertheless, the conclusions are essentially the same. The results did not indicate that any particular cultivar was more tolerant to drought than the others. This may just reflect the fact that durum wheat is a generally drought-tolerant crop and there was not much variation in drought tolerance among the cultivars tested.

The results provide no clue to a simple character that can be used as a measure of drought tolerance.

Reference

Hurd, E. A. 1964. Root study of three wheat varieties and their resistance to drought and damage by soil cracking. Can. J. Plant Sci. 44:240-248.

SOIL MANAGEMENT UNDER DRYLAND CONDITIONS OF CENTRAL ANATOLIA

Mengu Guler, Nedret Durutan, Mustafa Pala and Mehmet Karaca
Turkey

Cereals have always been the most important crop in Turkey with regard to acreage as well as production. Approximately 46% of the area sown is occupied by cereals (9 million ha). According to the latest statistics almost 50% of the total wheat yield is being produced in the Central Anatolian Plateau where summer fallow is being practiced. Since the ecology of the region determines the agricultural system practiced it is worthwhile to discuss the climatological and soil data of the Central Anatolian Plateau.

Scarcity of rainfall and its seasonal pattern are the most remarkable characteristics of the region. Average annual rainfall varies considerably and ranges from 250 to 400 mm depending on the locality. For the whole region the long-term annual precipitation average is 382 mm.

The length of the drought period is very important with regard to moisture storage in the fallow year as well as crop growth in the crop year (Figure 1). After harvest of the crop there is a 3-month arid period beginning around August and persisting until the end of October. This period is followed by a long humid season usually from November through June. The winter and spring months have more total precipitation accompanied by lower temperatures and higher humidities compared with summer and fall. Within the fallow year, another drought season begins around the end of June and continues until the end of October. From the water storage point of view this is the most important period.

Most of the soils where wheat is grown in Turkey are fine textured clay soils, containing 30-70% of clay, particularly in the Central Plateau. These soils have a low water intake rate with very slow downward movement into the subsoil but when evaporation takes place at the soil surface considerable upward movement occurs. Both of these characteristics are responsible for moisture losses. Soil depth is another critical factor in considering the summer fallow system. In some areas of the Central Anatolian Plateau soils are relatively shallow and remarkably limit the yields.

Although there are several factors determining the cropping sequence, annual precipitation appears to be the most important one. In the Plateau a fallow-cereal rotation is the chief cropping sequence. The effect of fallowing on yield compared to annual cropping of wheat is considered to be beneficial.

Wheat Research and Training Center, Ankara

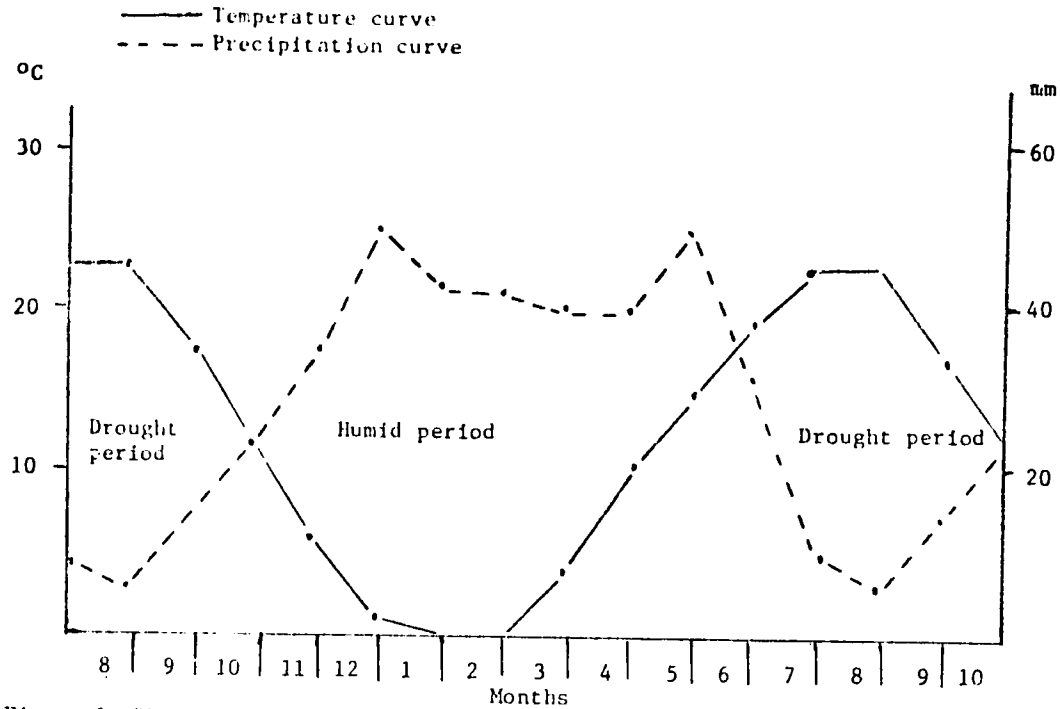


Figure 1. The clima-diagram of the Central Anatolian Plateau in the fallow period.

In the period of 1976-1978 a series of experiments were conducted in various localities of the Central Anatolian Plateau for the purpose of determining the relationship between wheat grain yields and available water. Figure 2 shows the relationship between the wheat grain yield and available water. Analysis of these data using linear regression techniques gave a correlation coefficient of 0.77 which was significant at the 1% probability level. The regression equation between the wheat grain yield and available water is as follows:

$$Y = 1.41\ (Aw) - 34$$

Y = Wheat grain yield (kg/da)
Aw = Available water for crops use (mm)

This equation indicates that 34 mm of available water is required to grow the crop to where wheat production starts and that 14 kg of grain yield per decare is produced by each additional 10 mm of water available to the crop.

In order to determine the available precipitation some assumptions are required. The assumptions listed here are an estimation of winter through summer precipitation used efficiently during the crop year, an average of published values of basic water requirements and water use efficiency values from the Pacific Northwest.

Assumptions:

1. 50% of the annual precipitation is received in the period of November through March. About 60% of the precipitation received in this period is available for crop use.

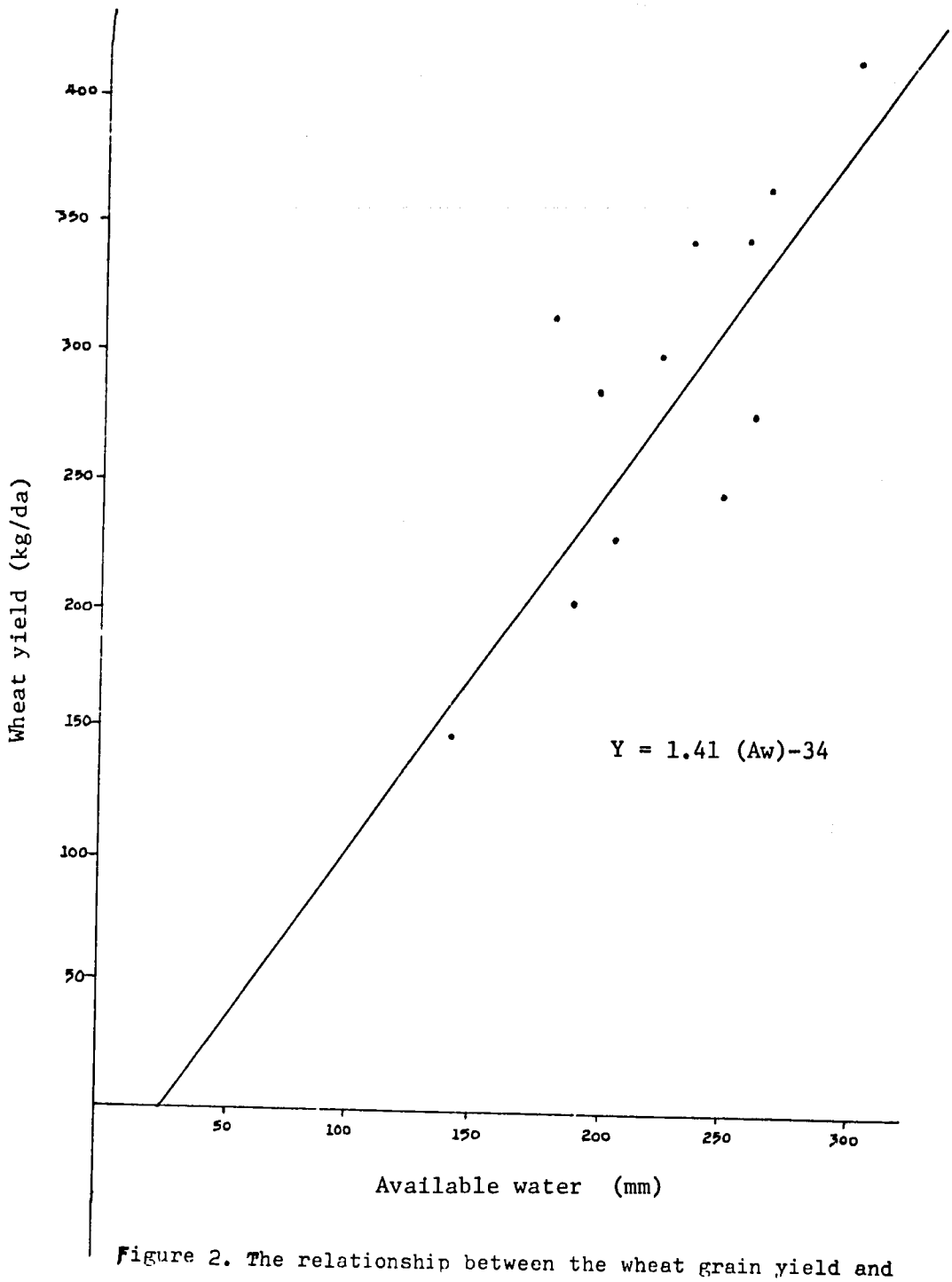


Figure 2. The relationship between the wheat grain yield and available water under the ecological conditions of Central Anatolian Plateau, 1976-1978.

2. 30% of annual precipitation is received during April through June and 85% of this is effective for crop use.

Under various annual precipitations the calculated precipitation values available for crop use depending upon the assumptions mentioned above are listed in Table 1.

Table 1. Various annual precipitation amounts and calculated precipitation available for crop use.

Annual precipitation (mm)	Calculated precipitation available for crop use (mm)
300	167
400	223
500	278
600	333

Table 1 indicates that the crop has a chance of utilizing 56% of the precipitation that occurs in the growing period under regional conditions.

In research conducted in the Central Anatolian Plateau, moisture supplies were determined in the fields under annual cropping and fallow-wheat cropping systems. In annually cropped fields average moisture supply at seeding time was found to be 100 mm below the permanent wilting point. On the other hand, in the fields where a fallow system was practiced the amount of moisture was at least at the permanent wilting point at seeding time. These data indicated that, in an annually cropped field, the first 100 mm of available precipitation received after seeding will be used to bring the soil up to its wilting point before the crop will begin to grow. On the other hand, having the moisture supply at least at the wilting point level, the crop in a fallowed field gains an advantage of using the available precipitation immediately.

The precipitation available for crop use in the growing period in different cropping systems, considering the 100 mm of difference, under various annual precipitation levels of Central Anatolian Plateau are given in Table 2.

Table 2. Available precipitation levels under the systems of annual cropping and fallow-wheat in Central Anatolian Plateau on the basis of annual precipitation.

Annual precipitation (mm)	Available water (mm)	
	Annual cropping	Wheat-fallow
250	39	139
300	67	167
350	94	194
400	122	222
450	150	250
500	178	278
550	205	305
600	233	333

By using the regression equation given before, several yield levels are calculated and given in Table 3.

Table 3. Estimated yield levels in a two year period under the systems of annual cropping and fallow-wheat.

Annual precipitation (mm)	Total yield in 2 years (kg/da) by annual cropping	by fallow-wheat
250	42	162
300	121	201
350	197	240
400	276	279
450	355	319
500	434	358
550	510	396
600	589	436

As is seen from Table 3, in up to 400 mm of annual precipitation, yields obtained from the fallow-wheat system are higher than the yields obtained from 2-year annual cropping. Above 450 mm of annual precipitation yields of annual cropping begin to increase and may become more profitable than the fallow-wheat system.

In the region annual precipitation varies greatly by years. Consequently, in the areas where the annual average is 450 mm or higher, the frequency of having precipitation below that level must be taken into consideration. In order to decide which system is profitable economical analysis is required.

There is another practical problem which also must be taken into consideration. From economical and environmental points of view the fallow-wheat system has an advantage, compared to annual cropping, with regard to weed control. Most of the weeds, particularly the grassy weeds that build up rapidly in annually-cropped fields, can be effectively controlled by tillage during the fallow period of the fallow-wheat cropping sequence. As pointed out in the preceeding discussion, the fallow wheat cropping sequence appears to be the most suitable system for balancing the soil and climatological conditions of Central Anatolian Plateau.

Best tillage system for the region.--In the dryland cereal production areas of the world there are two prevailing fallow systems. One of the systems is stubble mulching in which stubble remains on the soil surface; the other system involves creating a dust mulch on the surface by succeeding tillage operations with various implements. Because of the various climate and soils found in the dryland agricultural regions no single formula can be prescribed for a soil management system that would optimize soil water storage for all regions. It should be remembered that successful application of the summer fallow system depends on a sensitive balance between climatological and soil factors.

In the Central Anatolian Plateau annual precipitation is not sufficient for annual cropping. During the fallow year efforts

are made to enhance infiltration in the rainy spring and to prevent evaporation especially during the dry and hot summer, through use of a dust mulch. The dust mulch is formed by breaking up the soil near the surface and providing finely divided soil aggregates.

Research conducted on the Central Anatolian Plateau showed that fall tillage does not improve water storage in the soil profile during fall and winter. Deeper penetration of water without any interference is promoted by cool temperatures, dry soils, stubble land and particularly by low intensity of precipitation that occurs mostly in the form of snow. These data strengthen the idea that tillage should begin in early spring of the fallow year.

During the rainy spring, precipitation is usually accompanied by higher relative humidity and lower temperature as compared to summer. Increasing the soil infiltration capacity is the main objective in this period. Efforts also are made to prevent weed growth on the fallow land to inhibit water loss through transpiration.

Research conducted in the region by the Central Anatolian Agricultural Research Institute indicated the effects of various tillage equipment on infiltration capacity and rate. The data (unpublished) showed that the moldboard plow is the most effective equipment for increasing infiltration rate and capacity. Another study that was carried out in the region by the same Institute indicated that the moldboard plow also is very effective in controlling weeds, particularly Bromus tectorum.

By plowing at a depth of 20 cm in early spring, dust mulch formation is initiated. This initial tillage facilitates water absorption by the soil during spring rains. It also decreases the upward transmission of water in liquid form although, remarkably, capillary continuity does not occur. When soil is in the proper condition, plowing results in a good aggregation and granulation which works as a barrier against wind erosion.

Soil and water lost by surface runoff can be another problem in the region, but research data obtained showed that surface runoff is not a problem for fields with a slope of less than 3%. Contour tillage on 3-8% slopes results in increasing the rate of infiltration to take all the rainfall into the soil.

After the initial tillage the objective is to decrease evaporation. Research conducted in the region indicated that sweeping at a depth of 10-12 cm provides small clods and decreases the porosity of the tilled layer. Loosening the soil surface with a sweep shallower than initial plowing breaks the capillary continuity with the deeper layer and, consequently, hastens the dry layer formation which increases resistance to upward water movement.

As the temperature increases following the rainy period the relative humidity decreases. These changes in the above-ground

environment favors vapor phase flow to the surface. The rate of vapor phase flow is also controlled by the temperature difference across the dust mulch.

Sweeping at the beginning of summer coincides with weed growth. At this time soil surface is covered with small clods. The sweep followed by spike tooth harrow decreases clod size and helps to eliminate weeds.

During the summer, sweeping may be repeated several times depending on crust formation and weed growth following rains. Thickness of the mulch layer is important in decreasing heat exchange between the atmosphere and the soil. At the Central Anatolian Agricultural Research Institute a study is being conducted for the purpose of determining the effect of thickness of the mulch layer. Although the study has not yet been completed, 7-9 cm thickness seems the most proper one.

The three-phased system provided by the dust mulch system is shown in Figure 3. The low porosity of the upper layer decreases moisture loss by increasing diffusion resistance. The lower layer has a higher porosity and it insulates the underlying moist soil thermally and limits the upward transmission of water.

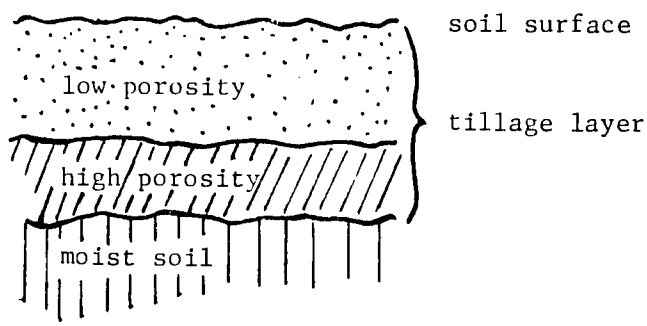


Figure 3. The three-phased system proper for the Central Anatolian Plateau.

Adaptive research in the region.--In five provinces of the Central Anatolian Plateau adaptive research trials were conducted in farmers' fields for 5 years. The purposes of these were to demonstrate the improved wheat production techniques to determine the adaptation of the results obtained from previous experiments and to estimate the yield situation and potential of the region. At each location the average yields were compared with those from adjacent farmers' fields.

The comparisons (Figure 4) showed that wheat yields from adaptive research trials were 88% more than wheat yields from neighboring farmers' fields. In other words, the wheat production system recommended by the Central Anatolian Agricultural Research Institute resulted in 88% higher yields. These results indicate that, in the region, it is possible to increase wheat production substantially by the application of the improved techniques.

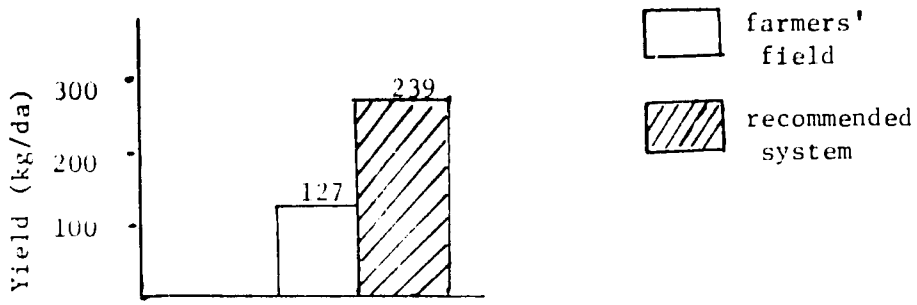


Figure 4. Comparison of the yields obtained from farmers' fields and recommended system, 1973-1977.

References

Allmaras, R. R., W. W. Nelson, and E. A. Hallauer. 1972. Fall versus spring plowing and related heat balance in the Western Corn Belt. Tech. Bul. 283. Minn. Agri. Exp. Sta., St. Paul. 22 p.

Akalan, I. 1974. Toprak ve Su Muhafazasi. A.U.Z.F. Yayinlari 532. Ankara Universitesi Basimevi.

Bolton, F. E. and D. E. Booster. 1977. Tillage, moisture conservation and water use efficiency for dryland cereal production in winter rainfall regions. Proc. of An International Symposium on Rainfed Agriculture in Semi-Arid Regions. California, USA.

Burnside, O. C., C. R. Fenster and C. E. Domingo. 1968. Weed control in a winter wheat-fallow rotation. Weed Sci. 16: 225-258.

Devlet Meteoroloji Isleri Genel Mudurlugu. 1968. Turkiye ve Cografi Bolgelerin Bazi Meteorolojik Elemanlarina ait Aritmetik Ortalama ve Standart Ayrilis Olcusu Degerleri. Ankara.

Fenster, C. R. 1974. Soil management research and farmer practices in the Great Plains of North America. Second Regional Wheat Workshop Proc. Ankara, Turkey.

Guler, M. N., M. Durutan, M. Pala ve M. Karaca. 1979. Nadas Yontemleri Uzerine Bir Inceleme. Orta Anadolu Zirai Arastirma Enstitusu, Ankara (in print).

Guler, M. 1980. Bugday Verimi ile Kullanilan Su ve Azot Miktarlari Arasindaki Iliskiler. Ankara (in print).

Orta Anadolu Bolge Zirai Arastirma Enstitusu. 1977. Orta Anadolu'da 1970-1976 Nadas Toprak Hazirligi ve Yetistirme Teknigi Arastirmalari. Yayin No. 77-2. Ankara.

Orta Anadolu Bolge Zirai Arastirma Enstitusu. 1978. Orta Anadolu'da 1972-1977 Nadas Toprak Hazirligi ve Bugday Yetistirme Teknigi Arastirmalari. Yayin No. 78-1. Ankara.

Orta Anadolu Bolge Zirai Arastirma Enstitusu. Comparison of stubble fallow and black fallow systems under the conditions of Central Anatolian Plateau. (unpublished).

Pala, M., M. Guler, I. Unver, N. Durutan and M. Karaca. Orta Anadolu'da nadas donemi ilkbahar toprak isleme zamaninin bugday verimine etkisi (in print). Ankara.

Papendick, R. I. and G. S. Campbell. 1974. Wheat-fallow Agriculture. Why, How, When? 2nd Regional Wheat Workshop Proc. Ankara, Turkey.

Unver, I. 1978. Nadas Toprak Islemesinde Zaman, Derinlik ve Yontemlerinin Topragin Rutubet ve Sicaklik Degisimine Etkileri. University of Ankara, Faculty of Agriculture, Ph.D. Thesis. Ankara.

WHEAT PRODUCTION IN BANGLADESH - AN EFFECTIVE RESEARCH AND PRODUCTION APPROACH

M. A. Razzaque and A. B. S. Hossain
Bangladesh

Abstract

Wheat acreage in Bangladesh increased at an accelerating pace from 136,000 acres in 1965 to 654,000 acres in 1978. There was an increase in area of 40 percent over 1977 and in 1979 there has been more than a 100 percent increase over 1978. Average yields also more than doubled from 0.3 to 0.8 tons per acre due to the introduction of new varieties, increased fertilizer use and an effective seed production and extension program. The paper describes how research and production programs have made these spectacular achievements possible.

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Introduction

bangladesh has now become a wheat-growing country, although in the past, wheat was little grown and it was not recognized as a farmers' crop. The earlier varieties, IP52, IP125, Dirk, Kheri etc. were very low yielding (about 0.3 ton/acre), disease susceptible, long maturing and were subject to lodging.

With the introduction of high yielding varieties, the climate as well as soil was found to be suitable for successful wheat cultivation in the country. There is a potential for growing wheat in an area of up to 5.6 million acres under non-irrigated conditions and an additional 2.1 million acres under irrigation for a total area of 7.7 million acres (Reconnaissance Soil Survey, 1965-73). Although rice is the staple food, Bangladesh has been importing wheat to meet its food deficit for a long time. In this way, a change has taken place in the dietary habit of people so that wheat provides a supplement to rice. Moreover, milling machinery has become available all over the country and wheat flour is now consumed primarily as chapati (hand made bread), as bread loaves and as confectionery products.

The successful wheat cultivation became possible when an appropriate research and production program was initiated in 1975-76.

Production Trend

When high yielding varieties were released, the farmers increased the area of cultivation due to:

i) Three to four times more yield as compared with local varieties;

Bangladesh Agricultural Research Institute, Joydebpur, Dacca.

ii) Good performance, even in residual soil moisture as well as in partially irrigated conditions;
iii) Low cost of cultivation and coverage of 3-4 times more area with the same amount of irrigation water as required by winter grown rice;
iv) Assurance of next crop, Aus paddy/Jute etc. after the harvest of wheat;
v) Little problem with weed competition, diseases and insects.

In 1965-66 the area under cultivation was 136,000 acres. Only local varieties were grown with production at about 35,000 tons. In 1975-76, out of a total of 371,000 acres, 218,000 were seeded with HYVs with a production of 215,000 tons (raising per acre yield from 0.3 tons to 0.6 tons). In 1978-79, the area covered was 654,000 acres of which over 95 percent was in HYVs and production rose to 487,000 tons. In 1979-80, an ambitious program was undertaken to cover an area of 1.561 million acres with a production target of 1.40 million tons to compensate for the 1979 summer loss of rice caused by drought and later flood. The production obtained in different years is shown in figure 1.

Research Activities

Research on high yielding varieties was initiated in 1966-67. The varieties Mexipak 65 (Kalyansona) and Sonora 64 were found suitable. For successful cultivation of these varieties, the requirements of wheat growers were taken into consideration and accordingly research activities were strengthened in 1970-71 through manpower development in co-operation with CIMMYT, Mexico. Simultaneously the most promising materials selected from different International Nurseries were put into the national program and finally eight HYVs were released in order to cover more areas within a short span of time. Wheat research is being conducted in the following six areas:

a) Variety development--i) Since more than 75 percent of the area is under dryland cultivation, emphasis was put on finding suitable dryland varieties and as a result Kalyansona, Sonalika and Inia 66 were selected and recommended; ii) Such short duration varieties like Sonalike and Inia 66 were recommended for growing after the harvest of transplanted aman rice in December; iii) For cultivation in irrigated areas, Tanori 71, Jupateco 73 and Norteno 67 were released as medium long maturing varieties (110-120 days); iv) Three additional new varieties: Balaka, Doel and Pavon 76, suitable for cultivation under differenc situations, were released recently.

b) Agronomic practices--Agronomic practices for the recommended varieties suited for cultivation under both irrigated and dryland situations were developed and made available to the growers. Some of the important recommendations are: i) The best seeding time for medium long maturing varieties is the first two weeks of November and for short duration varieties the last two weeks of November. If the seeding is not possible within the stipulated period, seeding can take place two weeks late in either case and still provide a very acceptable yield level; ii) As seed drills are not in use,

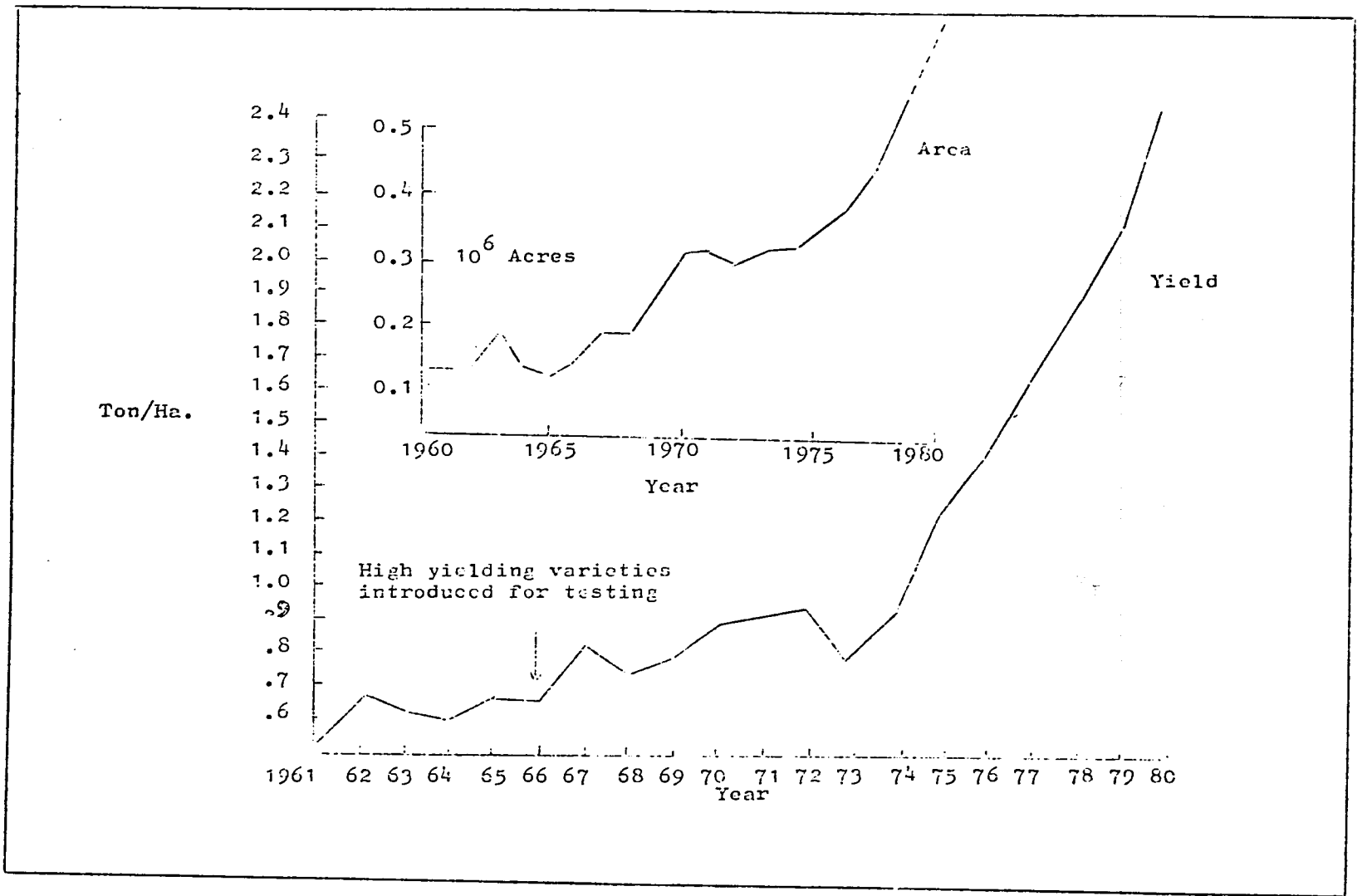

Figure 1. Wheat in Bangladesh.

growers are advised to use a seed rate of 100 Kg and 120 Kg/ha for non-irrigated and irrigated conditions, respectively. An additional 10-20 Kg of seed should be used if the seeding is delayed; iii) Fertilizer @ 60:60:40, 80:60:40 and 100:60:40 Kg. N, P and K/ha are recommended for non-irrigated, partial and fully irrigated conditions respectively; iv) Irrigation at crown root initiation (CRI), heading and grain filling stages are critical in the heavy red laterite type of soils and if only one irrigation is possible, it needs to be applied at CRI stage which will increase the yield 50 percent above that of the non-irrigated condition. This one irrigation is sufficient to raise the crop in most of the wheat areas.

c) Crop protection measures--Weeds, diseases and insects do not appear to be major problems in Bangladesh at this stage. However, sporadic infestations of pests and diseases such as loose smut, wire worms and aphids have been noted. For their control, appropriate pesticides are recommended. No herbicides are as yet used by the growers.

d) Seed storage--Under a highly humid climate, insect infestation in storage is a major problem. Proper technology for seed preservation was developed and made available to the farmers. Sealed tin containers, kerosene/biscuit tins, petrol or diesel drums, thick polythene bags have been found to be best for storage and the farmers have adopted this technique of seed preservation.

e) Farmers' field experimentation/demonstration--To determine agronomic requirements in a specific location, field trials and demonstrations with new varieties and agronomic practices are conducted on farmers' land and appropriate recommendations are made to the farmers.

f) Transfer of technology--Research findings and recommendations are communicated to the growers through booklets, leaflets, folders, radio broadcasts and other audio-visual means. Training sessions are also provided to extension personnel, progressive farmers and others involved in the production programs. Field days are organized during the crop season in which local administrative personnel and surrounding farmers participate in acquiring practical and technical "know-how". The farmers also are benefited by direct contact with the researchers. Workshops and seminars also are organized involving concerned personnel of different disciplines.

Production Activities

When the performance of the high yielding varieties was found satisfactory and expert opinion was available for successful wheat cultivation in the country, an ambitious production program using the HYVs to replace the local ones was drawn up in 1975-76. In subsequent years seed imports have been continued to provide for expansion. In 1979-80, a massive program was launched to compensate for the loss of rice caused by drought in the previous year. Some of the important steps that were taken follow:

a) Seed import--As the seed production program at this stage provided only about 4,000 tons, weeds of such recommended varieties as Jupateco 73 from Mexico and Kalyansona and Sonalika from India were imported in 1975-76. With these imported and local seeds an area of 218,000 acres was covered by HYVs replacing the local varieties. In subsequent years further quantities of seed were imported as follows:

Year of import	Varieties	Quantity in tons.
1976-77	Sonalika, Tanori 71, Jupateco 73	880
1977-78	Inia 66, Tanori 71, Jupateco 73 and Sonalika	2,200
1978-79	Sonalika, Inia 66 and Jupateco 73	2,900
1979-80	Sonalika, Inia 66 and Pavon 76	14,000

b) Seed production--When production of wheat was found to be profitable the Bangladesh Agricultural Development Corporation (BADC), the only seed producing agency in the country, began to multiply seeds on their farms and subsequently in the growers' fields. In support of this program several seed processing centers with storage facilities were built. In 1975-76 only 1,300 tons of seed were produced but by 1979-80 seed production had risen to 11,000 tons.

Farmers were advised as to how to preserve their own seed at the farm level. At present, 80 percent of the total requirement for seed is being met from their own stocks. A survey conducted in the year 1976-77 on "Wheat Seed Storage under Farmers' Conditions" revealed that about 80 percent of the farmers were able to preserve their seeds in a highly viable condition.

c) Extension--The Directorate of Agriculture (Extension and Management) dramatically increased its activities to provide wide publicity on how to cultivate high yielding varieties of wheat. This was done through organizing block farms in areas where there were adequate sources of water and involved field demonstrations of varieties, fertilizer rates, sowing time etc. as a means of convincing the farmers of the value of the varieties and agronomic practices. The best farmers were awarded prizes for the outstanding yields in each year.

d) Support price--To encourage wheat production in the country, the support price of grains (a little over the market price) and seeds has been provided since 1975-76. Simultaneously, the Department of Food began procuring wheat. Initially, 5,000 tons were procured but this was raised to 52,000 tons in 1978-79. In 1979-80 the target has been fixed at 250,000 tons.

e) Supply of other inputs--Timely credit for fertilizer was made available to farmers.

Conclusion

The recurring food gap (1.5-2.0 million tons) can easily be removed through wheat production alone. This season, Bangladesh expects to have a record harvest of over one million tons. In

this context a National Plan has been drawn to raise present acreage under wheat to 4.0 million acres with a production target of 4.0 million tons by 1985. This ambitious target now appears to be entirely feasible if infrastructure growth is carefully planned as production rises.

References

Anonymous. 1978. Bangladesh Agricultural Statistics, Ministry of Agriculture. Dacca.

_____. 1979. Wheat Newsletter. Nos. 1-5. Bari. Dacca.

Brammer, H. 1965-73. Reconnaissance Soil Survey. Department of Soil Survey. Dacca.

Razzaque A., A. B. S. Hossain, A. Ahmed and M. Hoque. 1978. Wheat seeds and their storage under farmers condition. Proceedings of the Bangladesh Association for Advancement of Sciences. Chittagong University.

PRODUCTION PROBLEMS AFTER 18 YEARS OF GROWING SEMI-DWARF WHEATS IN THE PACIFIC NORTHWEST

C. J. Peterson and R. E. Allan
United States

Abstract

Semi-dwarf wheat varieties have been grown in the Pacific Northwest since 1961, increasing production by 30 percent. Cereal diseases (Cercosporella foot rot, leaf rust and barley yellow dwarf) and insects (green bugs and oat-bird cherry aphids) are more of a problem today because of the new management practices used in the production of semi-dwarf wheat. Emergence of the semi-dwarf wheats needs considerable improvement because poor emergence limits their adaptation. Grain yield increases are slower to come by today but new lines indicate that advancement is still possible. The milling and flour characteristics of the semi-dwarfs have been improved with the development of new cultivars.

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Wheat is the principal agricultural crop in the Pacific Northwest and has been grown in the region since the early 1800's. The Pacific Northwest includes northern Idaho, Oregon, and Washington. The region receives most of its moisture between September and June and the summers are typically hot and dry. Excellent quality wheat can usually be harvested and delivered to market. Precipitation and temperature vary greatly over the area and this makes it possible to produce pastry, bread, and durum wheats. In 1978, approximately 5.5 million metric tons of wheat were produced in the Pacific Northwest. Of this amount 84% was soft white (spring and winter), 9% was soft white club (winter) and 7% was hard red (spring and winter). There was also a small amount of durum.

The environment is not only ideal for the production of wheat, but also for the development of many wheat diseases. The main diseases present in the region are common bunt (Tilletia foetida (Wall) Liro), dwarf bunt (Tilletia controversa Kuhn), stripe rust (Puccinia striiformis West), leaf rust (Puccinia recondita Rob. ex. Desm. f.sp. tritici), Cercosporella footrot (Pseudocercosporella herpotrichoides (Fron.) Dei.), Fusarium dryland footrot (Fusarium culmorum (Smith) Sacc.), take all (Gaeumannomyces graminis var. tritici Walker), snow mold (Typhula Spp), Cephalosporium stripe (Cephalosporium graminium Nis. & Ika.), powdery mildew, (Erysiphe graminus f.sp. tritici), wheat streak mosaic and barley yellow dwarf.

The expected life of a variety was 5 years before the first semi-dwarf wheat was released to the wheat producers. The early varieties declined in production because they became susceptible to new races of common bunt. Therefore, for many years the main emphasis of the breeding programs in the Pacific Northwest was on the development of bunt resistant varieties. A chemical seed treatment

Washington State University, Pullman.

(hexachlorobenzene) for control of common bunt was released in 1956 to the wheat growers. In that same year, 'Omar', a very resistant winter wheat also was released to the growers and since then the combination of chemical control and resistance has effectively controlled common bunt.

The introduction of the semi-dwarf growth habit of Norin 10 into the wheat breeding program at Washington State University in 1949 marked the beginning of new records in production efficiency from winter wheat (6). The change from standard height wheats to semi-dwarfs occurred rapidly. The first semi-dwarf winter wheat, 'Gaines', developed in the USA was released to wheat producers in 1961. Three years later Gaines was planted on 60% of the wheat acreage in the Pacific Northwest. By 1978, 83% of the soft white wheat production in the Pacific Northwest was of semi-dwarf wheat varieties. Production of semi-dwarf wheats brought about many changes in management practices. Higher rates of nitrogen were possible because the semi-dwarf wheats were more resistant to lodging and could make more efficient use of nitrogen (3). On the average, Omar used 1.4 kilograms of nitrogen to produce 27.2 kilograms of wheat [illegible] Gaines requires 1.2 kilograms. Production of semi-dwarf varieties encouraged the use of earlier seeding to control erosion and increase production. Grain yields average 19.7 Q/Ha for the [illegible] years (1944/1961) before Gaines/'Nugaines' and 28.2 for the next [illegible] years (1962/1979) for a 43 percent increase in production. Part of the semi-dwarf wheat yield advantage is genetic gain and part is due to the increased use of fertilizer and improved management.

Plant characters that appear to be associated with high production include high tillering capacity, early spring growth, stiff straw, shatter resistance, disease resistance, more kernels per spike, and semi-dwarf plant height (5). Early planting in the higher rainfall areas resulted in higher yields and minimized soil loss during the fall and winter. Another advantage of early seeding was the control of weeds through increased competition. When the standard height varieties were sown early, they grew too vigorously and lodged. This resulted in decreased production.

New and old problems have accompanied the high production attained through the use of semi-dwarf wheats and high fertilization levels. Poor emergence, lodging, disease, shallow crown depth, low test weight, and poor quality were problems associated with the early semi-dwarf varieties. Semi-dwarf wheats had shorter coleoptiles and slower seedling growth rates than the tall varieties (2). Difficulty was encountered in getting proper stands with the semi-dwarf wheats when sown 10 to 13 cm. deep in order to reach moisture, especially with early seedings in hot soil. Allan et al., (1) have shown that coleoptile length correlates closely with emergence and that the optimum coleoptile length occurs at 15.5 c. They also found that high temperatures inhibit coleoptile elongation. The coleoptile length and emergence rate of new semi-dwarf wheats have been improved but at the expense of lodging resistance. 'Luke'

and 'Sprague' have coleoptiles about 10 percent longer than Nugaines (Table 1). A recently identified semi-dwarf VH079029 has a coleoptile 27 percent longer than that of Nugaines.

Lodging has been a problem in the high production areas of the Pacific Northwest. O. A. Vogel realized that he needed to reduce the plant height of the varieties in order to reduce lodging. The first semi-dwarf varieties reduced the amount of lodging but did not completely solve the problem.

Table 1. Coleoptile length of five soft white winter wheats.

Selection	Coleoptile length (mm)
Nugaines	62
Luke	69
Sprague	69
Daws	50
VH079029	85

The most recent semi-dwarf wheats, 'Daws' and 'Stephens', have stiffer culms and display greater resistance to lodging.

The dense canopy formed by culms, leaves, and spikes over the soil surface provides a microclimate well suited for the development of several cereal diseases, many of which were curiosities before semi-dwarf varieties were grown. Irrigation and early planting have aggravated the problem. Wheat is used as a cover crop on the light sandy soils to control wind erosion and therefore is sown almost every month of the year. The presence of green wheat all year constitutes a giant incubator for the development of every month of the year. The presence of green wheat all year constitutes a giant incubator for the development of airborne diseases and insects. Previously most vegetation was dead during late July and August. The airborne diseases stripe rust, leaf rust, and barley yellow dwarf, currently are major problems. Of this group, only stripe rust was a serious problem before the introduction of semi-dwarf wheats. Stripe rust has been controlled by developing varieties with stable adult plant resistance. Gaines has a moderate level of adult resistance and Nugaines possesses an even higher level. Luke, released in 1971, has yet a higher, nearly immune type of adult plant resistance.

The semi-dwarf wheats make better use of the growing season than the previous varieties. Maturity may be delayed if adequate moisture and moderate temperatures occur after flowering. When this happens, the crop may be damaged by leaf rust because this disease appears late in the season. All of the semi-dwarf winter wheats currently grown in the Pacific Northwest are susceptible to leaf rust. 'Hyslop' was resistant when released but a race of leaf rust able to attack it has become prevalent. A plant introduction from Turkey (PI178383) is one parent in most of the varieties grown in the region. PI178383 was an excellent source of stripe rust and bunt resistance. Unfortunately, it is very susceptible to leaf rust.

Cercosporella footrot increased dramatically in the early sown fields with the use of semi-dwarf wheats. The microclimate produced by early seeded semi-dwarf wheat plants provides ideal growing conditions for the footrot organism. Lush growth in the fall with moist conditions and a mild winter are needed for maximum footrot development. Although Nugaines has some tolerance to Cercosporella, its grain yield has been reduced 50-70 percent under severe foot rot conditions. European lines with moderate footrot resistance have been combined by crossing with our semi-dwarf lines and lines such as Cerco (a soft red winter wheat) that have good resistance have been developed. New varieties Luke, Stephens, 'Barbee', and 'Paha' provide some footrot protection for mild infection conditions but do not have sufficient resistance for the high infection conditions. Chemical control using benomyl is expensive and needs to be replaced by the use of resistant varieties.

Cephalosporium stripe was an isolated problem in the heavy soil areas of Washington and Idaho before Gaines was released. Gaines and Nugaines were moderately resistant to Cephalosporium stripe and the disease caused very little damage. The new semi-dwarf wheats, Hyslop, 'McDermid', and Stephens are very susceptible and the disease is a major problem on these varieties (Table 2).

Increased use of irrigation and early seeding has made fall conditions ideal for the buildup of large populations of greenbugs (Schizaphis graminum Rond) and oat-bird cherry aphids (Rhopalasiphum padi L.). These aphids are vectors of barley yellow dwarf virus and this disease is causing considerable yield loss in the fields that are sown early in the fall. The green bug has destroyed parts of some fields and farmers are using insecticides to control the aphid. Currently grown winter wheats possess no resistance to the green bug.

Table 2. Reaction of seven winter wheats to Cephalosporium stripe. A 1 to 9 rating system was used in which 1 = low infection type and 9 = high infection type.

Variety	Rating	Yield (Q/Ha)	Height (Cm)
Tyee	3.8	48.7	82
Barbee	5.5	44.4	86
Nugaines	2.0	47.9	80
Luke	2.5	48.3	82
Stephens	8.7	27.4	64
McDermid	9.0	26.4	65
Daws	3.3	51.0	82

Other cereal diseases such as flag smut (Urocystis apripyi (Preuss) Schroet.), snow mold, and dwarf bunt have increased since the release of semi-dwarf varieties. The increase of flag smut can be attributed partially to the semi-dwarf growth habit and the increase in early, deep seeding. Early seeding also has increased the incidence of snow mold but the large plants also

provide some protection against the fungus. Late, shallow seeding in the recrop area has increased the incidence of dwarf bunt.

Semi-dwarf varieties provided less competition to weeds creating many new management problems. Broadleaf weeds are kept under control with the use of chemicals, but the grassy weeds now present serious problems. Downy brome (Bromus tectorium L.), goatgrass (Aegilops cylindrica Host.) and wild oats (Avena fatua L.) compete better than the wheat for moisture and nutrients when they emerge first. Preliminary data have shown a considerable difference among varieties in their ability to compete with weeds and Luke will compete with wild oats better than Nugaines.

Early semi-dwarf wheats were criticized as having mediocre milling quality. Omar, a soft white club wheat, was the principal variety grown in the Pacific Northwest before the release of Gaines. It was an excellent milling wheat. Milling data indicated that Gaines did not mill as well as Omar and the millers were concerned. They found, however, that by making a few adjustments in their mill that Gaines would mill satisfactorily. Milling characteristics of the semi-dwarf wheats were improved with the release of Nugaines and Luke (Table 3). Luke produced almost as much flour per pound of wheat as Omar.

Table 3. Milling properties of six soft white winter wheats.

Varieties	Flour yield	Milling score
	Common types	
Gaines	70.7	88.2
Nugaines	72.6	90.0
Luke	74.8	93.4
Daws	72.0	88.6
	Club types	
Paha	75.0	93.0
Tyee	74.8	91.5

Yields have continued to increase with the release of new improved semi-dwarfs. Kharkof, the long time check in the yield nurseries, averaged 29 quintals per hectare at five locations during 1972 to 1978, whereas Nugaines produced 42 quintals per hectare for a 45 percent increase in grain yield. Yields have been advanced by 7, 6 and 6 percent respectively for Hyslop, Luke, and Daws over that of Nugaines (Table 4). Daws was released after Luke and Hyslop and produces slightly less than Hyslop but it is superior in winter hardiness. The correlations (Table 4) between Nugaines, Hyslop, Luke and Daws show that they all responded similarly to the many different environmental conditions. The correlations between Kharkof and the other wheats are somewhat lower but this may be due to the susceptibility of Kharkof to stripe rust.

Table 4. Yield (Q/Ha) and correlation coefficient data on five winter wheats grown at five Washington locations with two fertility treatments during 1972-78. During that time two nurseries were lost so data are based on 66 tests.

	Kharkof	Nugaines	Hyslop	Luke	Daws
Kharkof	28.86*	.70**	.67	.65	.59
Nugaines		42.12*	.86	.88	.85
Hyslop			45.40*	.92	.84
Luke				44.73*	.86
Daws					44.91*

*grain yield (Q/Ha).
**correlation coefficient.

Regression coefficients have been used by Finlay and Wilkinson (4) to express the adaptation of a variety. They suggest that the regression of the yield of a variety on the nursery mean from a number of test sites will give a good indication of its adaptation. A regression coefficient of less than 1 indicates general adaptation and above 1 indicates specific adaptation. Nugaines (Table 5) has a regression coefficient of .98 and is generally adapted, whereas, Hyslop, Luke, and Daws are somewhat more specific in their adaptation.

Table 5. Grain yield (q/ha), correlation coefficient and regression coefficient data on five winter wheats and the nursery mean (120 Selections). Data are from 56 test sites (five locations, two treatments, and six years; data from four test sites were lost).

Variety	Yield (q/ha)	Correlation coefficient	Regression coefficient
Mean of Nursery	43.1	1.00	1.00
Kharkof	29.2	.46	.52
Nugaines	43.1	.81	.98
Hyslop	46.4	.87	1.27
Luke	45.4	.92	1.12
Daws	46.0	.92	1.12

The regression coefficients for test weight (Table 6) show that Nugaines, Luke, and Daws are generally adapted. Their test weight is affected less by the environment than the test weight of Hyslop, the earliest variety in this group. The correlation coefficients show that the test weight of Hyslop closely follows that of the nursery. The test weight of Nugaines is less affected by the environment. Therefore semi-dwarf wheats have been developed that have either restricted or general adaptation to the region for grain yield and test weight.

Table 6. Test weight (kilograms per hectoliter), correlation coefficient and regression coefficient data on the nursery mean (120 selections) and five winter wheats. Data are from 56 test sites (five locations, two treatments, and six years; data from four test sites were lost).

Variety	Test weight (kg/hl)	Correlation coefficient	Regression coefficient
Mean of Nursery	59.1	1.00	1.00
Kharkof	60.7	.50	.82
Nugaines	61.0	.53	.90
Hyslop	59.2	.84	1.01
Luke	60.1	.65	.79
Daws	60.0	.71	.77

Summary

Semi-dwarf wheats have been grown in the Pacific Northwest since 1961, and even with the new problems they have created, Nugaines has remained in production longer than any previous major variety. Cereal diseases and insects are more of a problem because of new management practices used in the production of semi-dwarf wheat. Progress in research and the breeding programs has solved some of the problems but many remain. Grain yield increases are harder to achieve but new lines indicate that advancement is possible.

References

1. Allan, R. E., O. A. Vogel and J. R. Burleigh. 1962. The effect of temperature on coleotile elongation of three groups of wheat varieties. Wheat Inf. Service, Lib. of Genetics, Kyoto U., Kyoto, Japan, 14:12.
2. Allan, R. E., O. A. Vogel and C. J. Peterson, Jr. 1962. Seedling emergence rate of fall-sown wheat and its association with plant height and coleoptile length. Agron. J.:347-350.
3. Briggle, L. W. and O. A. Vogel. 1968. Breeding short stature, disease-resistant wheats in the United States. Euphytica Supplement. No. 1:107-130.
4. Finlay, K. W. and G. N. Wilkinson. 1963. The analysis of adaptation in a plant-breeding program. Aust. J. Agric. Res. 14:742-754.
5. Vogel, O. A., R. E. Allan and C. J. Peterson, Jr. 1963. Plant and performance characteristics of semi-dwarf winter wheats producing the most efficiently in eastern Washington. Agron. J. 55:397-398.
6. Vogel, O. A., J. C. Craddock, C. E. Muir, Jr., E. H. Everson and C. R. Rohde. 1956. Semi-dwarf growth habit in winter wheat improvement for the Pacific Northwest. Agron. J. 48:76-78.

THE USE OF WHEAT BLENDS AS A TOOL IN WHEAT PRODUCTION

D. J. Sammons and P. S. Baenziger
United States

Abstract

Wheat production in the developing world is characterized by unpredictability in management, environment, and production resources. Consequently, production strategies that may be suitable for the needs of the developed world may not fit well with the needs and realities that exist in the remainder of the wheat-producing regions. Breeders at CIMMYT (Centro Internacional de Mejoramiento de Maiz y Trigo) have recognized the unpredictability characteristic of wheat production in the developing world, and have responded to it in part by the release of wheat multiline composites developed for rust resistance. The conceptual framework for this work is a recognition of the danger of genetic uniformity in crops grown over wide areas. In other words, multilines confer a degree of stability in a relatively unpredictable disease environment. The extension of this concept of alternative production strategies designed to buffer against other environmental uncertainties is equally valid. Such procedures as intercropping, crop rotation, and periodic fallowing are examples of effective production practices that can provide a degree of stability in an unpredictable environment.

We propose another procedure that may also be suitable for insuring an element of stability in wheat production, and that could be especially suitable in the developing world. The procedure is to blend mechanically an assortment of genetically differing cultivars, and to grow them as a mixed stand. The cultivars are chosen to be complementary for specific traits of interest. In our work, we have blended four winter wheat cultivars into two, three, and four-way mixtures (blends) and compared their performance as blends to their performance in pure stands. The specific traits of interest in our work are grain yield, test weight, lodging, plant height, disease presence, winter hardiness, and grain quality. The experiment is continuing, but one year's data from two location appear promising. We have identified advantages for wheat production in blends for yield, disease presence, and test weight, although there are location interactions. Data on the other variables of interest do not currently suggest an advantage for them in blends when compared to pure stands.

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Department of Agronomy, University of Maryland, College Park, Maryland and U.S. Department of Agriculture, Beltsville Agricultural Research Center, Beltsville, Maryland.

Introduction

Plant breeders and other crop scientists have increasingly recognized the risks inherent in the production of genetically uniform crops. There is a large and growing literature documenting the genetic vulnerability of our major crop species. The 1970 southern corn leaf blight (Helminthosporium maydis) epiphytotic in the United States is only one of a number of significant crop disasters or near disasters that trace to the presence of genetically similar plants over wide areas. Similar epiphytotics of probable genetic origin include Victoria blight (Helminthosporium victoriae) in oats, the Irish potato famine of the 1840's, the Phylloxera disease problems in the French wine grape industry, the Panama wilt disease (Fusarium oxysporum) in Central American banana plantations, and the Helminthosporium oryzae epiphytotic in 1942 in Bengal rice fields, which resulted in a famine with widespread deaths (National Academy of Sciences, 1972).

In much of the developed world, nevertheless, genetic uniformity is the norm rather than the exception in crop production. The demands for uniformity are, in part, a response to market requirements and production practices in the characteristically highly mechanized agriculture of the developed world. Although these demands can be met by phenotypic uniformity alone, they are generally satisfied by strict genotypic uniformity. Such uniformity, however, does not necessarily insure quality, particularly nutritional quality. It simply makes it easier and more convenient to insure market quality and to meet production demands. Ease and convenience, however, are not adequate reasons for permitting the risks inherent in genetic uniformity to occur. As Simmonds (1962) argues, it is erroneous to believe "that strictly uniform crop populations are a universal ideal to be aimed at whenever possible." This is particularly true in the agriculture of the developing world, where small farmers are separated from disaster by only a thin margin, and can ill-afford the risks we may ask them to take in growing a genetically uniform crop.

If we are interested in the welfare of small farmers and rural families in the developing world (as well as in the agriculture of the industrialized world), we must start with the recognition that genetic non-uniformity is neither a sign of backwardness nor a mark of diminished quality. In fact, as will be shown, the genetic diversification of principal crop plants has much to offer the agricultural world in terms of reduced risks and stabilized performance, and appears to have a particular application in the poorer nations.

The purposes of this paper are:

1) to review pertinent literature on the subject of blends from both a practical and a theoretical perspective and; 2) to present preliminary data on the performance of wheat blends at two locations in Maryland.

Literature review

The practice of intentional crop diversification is not a new system (Warburton, 1915). Jensen (1952) points out "The principle of diversification is an old one with an application particularly suited to risk situations." Increasingly, agricultural scientists have focused on the principles that make these systems successful (American Society of Agronomy, 1976). Genetic diversity is inherent in the domesticated land races grown in subsistence agriculture in many parts of the developing world. Harlan (1975) pointed out that land races are derived through long evolution under domestication and are characterized by stability, dependability, and close adaptation to their local environments. They are also highly heterogeneous. They behave as well-integrated biological units, and are well-buffered against environmental fluctuations. In short, land races have a number of desirable characteristics from the point-of-view of a small farmer in the developing world who cannot afford to take risks. Unfortunately, land races are generally low-yielding, and consequently are rapidly being replaced by new, higher yielding cultivars as the apparent benefits of scientific agriculture are gradually made known to small farmers in the developing world. Often, however, the benefits of the new Green Revolution cultivars are tied to unavailable packages of production inputs, and are also limited by the risks inherent in their genetic uniformity. Increasingly, it is being recognized that the creation of new diversity is going to be necessary for the long-term success of the new cultivars as they replace the old diversity present in traditional cultivars. CIMMYT (Cimmyt Review, 1979) breeders already state that a main goal of their program is stable resistance to the rust disease complex on wheat, and they accomplish this goal by the intentional creation of genetic diversity through their multiline program. Similar work is reported for oats threatened by disease problems (Browning, et. al., 1963).

There are many ways in addition to the use of multilines to create diversity in crop situations, all of which have at least the potential of securing increased dependability and reduced risk in agricultural performance when compared with single-crop situations. Perhaps the most widely recognized forms of crop diversification are the systems known collectively as multiple cropping. In these mixtures of several to many crop species, it has been well-documented that the biological units created respond in a dynamic way to unpredictable and unpredicted environmental threats such that total crop failure is far less likely than in a single crop situation (American Society of Agronomy, 1976). This benefit arises from the fact that any reduction in performance due to stress effects on one component of the mixture can be compensated for by an enhancement of performance by another component such that total productivity of the unit is maintained. Part of the benefit of multiple cropping is its disruption of the crops' environment, which prevents the rapid build-up of pest organisms. Multiple cropping also spreads the crops' demands on the environment over longer periods of time than in

a monocrop situation. This is due to the fact that not all the components of the mixed stand have the same resource demands at the same time. Similar advantages can be obtained by crop rotation or crop-fallow systems of production.

In addition to multiple cropping systems, there are other possible procedures for the intentional creation of crop diversity. Alternative procedures are especially desirable in situations where mixed cropping (more than one crop species) is not wanted but diversity is still required to reduce risks and stabilize performance. For example, the production of improved, genetically heterogeneous, open-pollinated populations of maize as described by Eberhart and Sprague (1973) provides an opportunity for East African farmers to benefit from the yield advantages of improved germ plasm while also realizing the benefits of genetic diversity. For similar reasons, it has been suggested that the release of improved early generation bulk populations for on-farm production of self-pollinating crop species (such as wheat) may be desirable, although this is distinctly at variance with pure line practices in the developed world (Suneson, 1956). The diversity created in self-pollinating crops by such a precedure might be further enhanced by the appropriate choice of parental material, particularly the use of adapted parents in wide crosses to generate the bulk populations. An additional advantage from heterosis may be realized in these bulk populations. Another alternative for insuring diversity while allowing for local uniformity in self-pollinating or cross-pollinating species is the use of multiple pure stands deployed in a manner to avoid genetic uniformity over wide areas. Finally, diversity can be created within a self-pollinating species by the intentional mixing or blending of pure lines. This procedure is biologically analogous to that of multiple cropping, except that pure lines of a single crop species are mixed together rather than mixing different crop species.

The potential advantage of a blend or mixture of genetically dissimilar lines of a self-pollinating species over a pure stand is well-stated by Frankel (in Palvakul et al., 1973):

> "The blending of varieties in one crop, apart from its possible value as a yield stabilizer, may conceivably raise the composite yield of the blend beyond the means of its components' yields when grown separately. The differences in physiological requirements and growth rhythm of the component varieties may create better conditions for the individual plant in a blend than in a pure population, where the requirements of all members are closely similar as well as simultaneous."

Similar statements regarding the theoretical advantages of blends have been made by others (Jensen, 1952; Suneson, 1960; Allard, 1961; Frey et al., 1967; Browning et al., 1969; CIMMYT Review, 1979). Marshall and Brown (1973) present a mathematical model describing the advantages of blends, and conclude that the greatest advantages in terms of yield and stability are expected in blends composed of dissimilar lines grown across a range

of environments. This hypothesis has been empirically confirmed with soybean blends of unlike varieties (Mumaw and Weber, 1957). Marshall and Brown (1973) suggest particular advantages in crop performance for blends grown in unpredictable environments, since blends exhibit generalized adaptability rather than the relatively specific adaptability of pure lines. The use of blends, then, is recommended in environments in which the environmental variability exceeds the buffering capacity of the best line in the blend.

The selection of components for the creation of a superior blend, however, is not an easy or simple task. Every blend has a unique set of qualities and characteristics (Fehr, 1973), and some blends will perform better than others. It appears from the work of Suneson (1942, 1949) that the compatability of lines in a blended population cannot be predicted from the performance of lines in pure stands, and that superior lines may be suppressed, inhibited, or eliminated in mixed populations. These observations have been confirmed by many observers (Laude and Swanson, 1942; Schlehuber and Curtis, 1961; Jennings and Aquino, 1968; Jennings and de Jesus, 1968; Singh and Johnson, 1969; Khalifa and Qualset,1974; Blijenburg et al., 1975). The performance and stability of a heterogeneous mixture (i.e. "blending ability" (Fehr, 1973))is specifically dependent upon the number and characteristics of genotypes composing the blend, the nature of the environments in which the blend will be grown, and the relative frequencies of the genotypes in the blend (Grafius, 1966; Early and Qualset, 1971; Marshall and Brown, 1973; Walker and Fehr, 1978). We still do not have a good set of criteria for predicting favorable blends except for those based specifically on disease reaction. It appears that, at least at present, the identification of superior blends will require empirical data, which presents an enormous testing problem (Brim and Schutz, 1968). Early (1971) identifies the specific types of responses characteristic of blends in the following way:

Overcompensatory - blend performance exceeds the mean of the components grown as pure lines.

Undercompensatory - blend performance is less than the mean of the components grown as pure lines.

Complementary - blend performance is equal to the mean of the components grown as pure lines due to gains in performance of some lines being offset by losses in performance of other lines.

Neutral - blend performance is equal to the mean of the components grown as pure lines, and there are no apparent inter-line competitive effects.

The agricultural situation in much of the developing world, in in which both management practices and uncontrollable environmental factors are highly variable, suggest a particular usefulness for blends as a tool in improved production. It must be recognized in the development of this argument that the usefulness and value of blends is related primarily to their advantages in terms of stabilizing performance in an unpredictable, highly variable environment (Jensen, 1952; Marshall and Brown, 1973; Walker and Fehr,1978).

Specific yield advantages may or may not also be realized. But in marginal operations, in which risks cannot easily be taken, and in which crop failures cannot easily be absorbed, stability of performance must be an overriding concern and a primary goal of crop scientists.

At this point, it is helpful to review pertinent literature on specific crops with respect to performance of blends. In sum, a thorough review of the current literature supports the observation that crop blends offer, in general, increased performance stability across environments relative to pure stands, but that yield advantages are only infrequently obtained in spite of the theoretical considerations cited earlier. Yield advantages for blends relative to pure stands are reported for wheat (Chapman et al., 1969), barley (Rasmusson, 1968), and soybeans (Mumaw and Weber, 1957; Brim and Schutz, 1968), but these reports appear to be the exception rather than the rule, and only for the wheat data (Chapman et al., 1969) are statistically significant advantages reported for the blend yields. However, as noted earlier, the greatest advantage of blends is to be realized in their stability across environments. In fact, Shorter and Frey (1979) state that the use of blends to obtain yield advantages is probably unwarranted, and that, realistically, one should not expect blends to do much better than the mean of their components or, at best, the level of the best component. Stability advantages in blends are reported for corn (Funk and Anderson, 1964), oats (Shorter and Frey, 1979), and soybeans (Probst, 1957; Schutz and Brim, 1971). This stability is enhanced by increasing the complexity or diversity of the mixed population. Rasmusson (1968) reports for barley populations the greatest stability was observed in the most complex mixtures tested, those being bulk hybrid populations in which every plant was a differing genotype. However, he notes that differences among the entries in his tested populations were such that only tentative conclusions can be drawn. Allard (1961) notes, however, that for lima beans both productivity and stability were superior for bulk hybrid populations relative to their parents in pure stands. The advantages realized were associated with the ability of differing genotypes to exploit particular ecological microenvironments fully in each generation, and may also be related to heterosis in the bulk hybrid population. In these bulk populations, natural selection over a number of generations appeared to be eliminating the poorly competitive genotypes although, as has long been observed (Laude and Swanson, 1942; Suneson and Wiebe, 1942; Suneson, 1949; Schlehuber and Curtis, 1961; Jennings and de Jesus, 1968) the poorly competitive genotypes may not necessarily be poor types in pure stands. The advantage to be recognized is that of stability in the mixed stands.

An additional feature of importance in terms of the advantages to be realized in blends is that the advantages noted are accentuated as the environments in which the blends are grown become more stressful. This has been observed for oats (Frey and Maldonado, 1967), and rice (Roy, 1960), and suggested for wheat (Pandey et al., 1979). In each of these examples, the blends

performed well because the heterogeneity of the populations buffered them against the unpredictable environmental stresses that occurred during their growth and development. It is this buffering effect that is an important advantage for blends, and that makes their use particularly desirable in the agriculture of the developing world.

In spite of the above noted theoretical and observed advantages for blends, there are a number of reports in the literature in which advantages were not observed either for yield or for stability. In terms of yielding ability, Palvakul et al. (1973) observed no particular advantage in any of 28 barley blends tested relative to their components in pure stands, and further noted that populations of dissimilar components do not have significant yield advantages over populations of similar components. Schlehuber and Curtis (1961) observed no advantages for four-way blends of hard red winter wheat. Similarly, Patterson et al. (1963) report no yield advantages in 15 oat blends over their components in pure stands, and further state that oat performance was much more rapidly improved through breeding efforts (using two of the components of the blends as parents) than it was by using the blends themselves. The story is repeated for soybeans (Sij, 1975), rice (Jennings and de Jesus, 1968), and corn (Stringfield, 1959). In the rice data reported (Jennings and de Jesus, 1968), the yield of the blend components in pure stands substantially exceeded the performance of the blends.

The inconsistency of the reports summarized above illustrates the importance of careful selection and testing of components for blending. What is surprising are the several reports suggesting that blends not only do not have a yield advantage over component pure stands but also that they may be lacking in stability as well. Clay and Allard (1969) report a study of 23 mixtures of barley varieties in which the blends were inferior to their components in terms of stability of yield over a range of environments, even though the environments were described as heterogeneous. Likewise, Walker and Fehr (1978) report no stability advantages for 66 mixtures involving various combinations of 28 high-yielding soybean genotypes when compared to their components in pure stands across 12 environments. They note only a general trend for pure lines to be less stable than mixtures. Finally, Ross (1965) reports on a grain sorghum blend experiment in which 10 blends were observed for a five year period. The experiment did not support the hypothesis that blends would perform better under variable, often stressful, growth conditions.

Although the authors of the above anomalous studies do not attempt to explain their unexpected observations regarding blend stability, it appears that their results may relate to the way the blends were put together. As noted earlier, the greatest advantage to be derived from blends should be realized in blends composed of dissimilar varieties. Furthermore, if the blends are composed of essentially similar lines, then the performance of the blend may vary as much or more across environments as do the pure line components themselves (Marshall and Brown, 1973). This is a probable explanation for the results summarized regarding the apparent lack of stability advantage in some blends.

If it is true, as it appears to be, that blends of pure lines have specific advantages over the pure lines themselves in uniform stands with respect to stability of performance, then their use should be further considered, tested and perhaps promoted in the agricultural systems of the developing world. But are there problems that might preclude their further exploitation in these areas? It appears that the lack of both pheotypic and genotypic uniformity in blends will not be a problem, since traditional land races (which are currently being replaced by improved crop populations) are themselves non-uniform. This, subsistence farmers do not generally have production demands or expectations that require uniformity. A second, possibly more serious, problem with the use of blends in the developing nations is that their yielding performance is unlikely to be as great as the best pure lines currently available. Clearly, superior yielding ability is a desirable goal of any farming system. However, of at least equal importance is stability of performance, and it is stability for which blends are best noted. Thus, the production of well-tested, superior blends composed of high-yielding lines should provide farmers in the developing world with the stable performance they must have to survive, and, in the long run, should provide them with superior yields as well. A final problem, and one which will be difficult to overcome, is that farmers cannot save seed from blend populations for reuse the next season. Blends must be reconstituted every year to avoid expected rapid changes within blends due to competitive interactions among their components (Laude and Swanson, 1942; Suneson, 1949; Schlehuber and Curtis, 1961; Jennings and Aquino, 1968; Jennings and de Jesus, 1968; Singh and Johnson, 1969; Khalifa and Qualset, 1974; Blijenburg and Sneep, 1975). This problem is probably the single greatest constraint to the wide use of blends in the agriculture of the developing world at this time. The accurate annual reconstitution of blends of a self-pollinating species such as wheat will require a seed industry of some sort, which is generally not present in the developing nations. It will also require appropriate marketing channels to make it available to producers, and an educational/extension network to insure that blends are used to realize their full potential. These disadvantages, nevertheless, do not negate the potential value of further study of the use of blends to improve production of wheat and other self-pollinating species of the developing world.

Introduction to our study

In the concluding section of this paper we briefly summarize the preliminary results of wheat blend experiment that we are currently conducting. The experimental results for only one year and two locations are presently available, but they are of interest in several respects in that they support some of the observations of workers cited earlier in this paper. However, the interpretation of the data is limited by its brevity, and should be so recognized.

Materials and methods

All possible equal-proportional 2, 3 and 4-way blends of 4 winter wheat cultivars were grown and compared for performance to pure stands of the component cultivars at two locations in Maryland (Clarksville and Beltsville) in the 1978-1979 season. The four cultivars utilized are 'Blueboy' (B), 'Centurk' (C), 'Holley' (H), and 'Potomac' (P). Their characteristics are listed in Table 1. The component cultivars were chosen because they specifically complement each other with respect to a number of the characteristics described in Table 1. We feel that suitable blends of wheat lines may mask deficiencies in adaptation, hardiness, disease response, and grain quality in the component lines while maintaining high yield potential. The study is designed to test this hypothesis.

Table 1. Description of cultivars utilitzed in the 1979 wheat blend experiment grown at Beltsville and Clarksville, Maryland.

Cultivar	Class	Adaptation to location	Winter hardiness	Reaction to powdery mildew*	Test weight	Soft wheat baking quality
Blueboy	Soft Red Winter Wheat	Good	Good	Susceptible	Poor	Excellent
Centurk	Hard Red Winter Wheat	Poor	Excellent	Intermediate	Fair	Poor
Holley	Soft Red Winter Wheat	Fair	Fair	Resistant	Good	Fair
Pttomac	Soft Red Winter Wheat	Excellent	Excellent	Resistant	Excellent	Good

*Powdery mildew is *Erysiphe graminis* f. sp. *tritici*.

Planting was at a standard rate for the location (1 gm seed/ 39 cm of row in rows 30 cm apart and 3 m in length). Four-row plots were established, and the 15 treatments (4 pure stands, 11 blends) were replicated 4 times. Prior to planting, 22.4 kg N/ha, 67.2 kg P_2O_5/ha and 67.2 kg K_2O/ha were applied and incorporated. An additional 67.2 kg N/ha was top-dressed prior to the beginning of regrowth in the spring. Plots were scored for lodging, height, winter survival, and the occurrence of powdery mildew. At harvest, a yield estimate was obtained, test weight was measured, and seed samples were submitted to the USDA Soft Wheat Quality Laboratory in Wooster, Ohio, for testing of the baking quality. Only the data for yield were combined across locations.

Results

Yield

Yield data are summarized in Table 2 combined across both locations. Yields for two of the blends (B:C:P and B:H:P) did not differ significantly from the yield of the best pure stand (Potomac) in the study even though they each included a poorly adapted, poor-yielding component. In addition, five of the blends (B:C:H:P, B:C:H:, B:C:P, C:H:P, B:C) that included Centurk, the lowest yielding pure stand, yielded significantly more than Centurk. Both of these situations are of interest because they suggest that blends can yield as well as their best components, and also that components which yielded poorly have other desirable attributes (winter hardiness and powdery mildew resistance in the case of Centurk) can be masked in a blend.

Table 2. Mean grain yields combined over two locations for 1979 wheat blend experiment at Beltsville and Clarksville, Maryland.

Entry	Yield kg-ha^{-1}	
Blueboy (B)	2924	a b*
Centurk (C)	1571	g
Holley (H)	1976	d e f g
Potomac (P)	3049	a
B:C:H:P	2401	b c d
B:C:H	2474	b c d
B:C:P	2573	a b c
B:H:P	2620	a b
C:H:P	2078	c d e f
B:C	2293	b c d e
B:H	2230	b c d e
B:P	2517	b c
C:H	1788	f g
C:P	1870	e f g
H:P	2332	b c d e

* Means followed by the same letter are not significantly different (p=.05) by Duncan's Multiple Range Test.

Test Weight

Test weight data are summarized in Table 3. In most cases the test weight of a blend was not significantly different from that of its component lines in pure stands. However, for five blends (B:C:H:, B:C:P, B:H:P, B:C, B:H) containing the low-test weight cultivar Blueboy, the presence of Blueboy reduced the test weight of the blend significantly below that of the other components in pure stands. This is undesirable, although perhaps less significant than it might otherwise seem since the effect of reduced test weight was not manifested in a corresponding yield reduction in the blends containing Blueboy.

Table 3. Mean test weight of grain samples for 1979 wheat blend experiment at Beltsville, Maryland.

Entry	Test Weight kg-hl^{-1}	
Blueboy (B)	68.2	c d*
Centurk (C)	74.2	a
Holley (H)	73.4	a
Potomac (P)	73.8	a
B:C:H:P	71.3	a b c d
B:C:H	70.1	b c d
B:C:P	69.2	c d
B:H:P	69.3	c d
C:H:P	71.6	a b c d
B:C	68.0	d
B:H	67.5	d
B:P	70.6	a b c d
C:H	71.6	a b c
C:P	70.0	b c d
H:P	72.6	a b

* Means followed by the same letter are not significantly different (p=.05) by Duncan's Multiple Range Test.

Lodging

The lodging score data are presented in Table 4. Centurk and Holley lodge badly in our environment. However, four blends (B:C:H:P, B:C:H, B:C:P, B:C) containing Centurk and six blends (B:C:H:P, B:C:H, B:H:P, C:H:P, B:H:, H:P) containing Holley lodged significantly less than their weak-strawed component. This suggests that a desirable but poor-standing type (Holley is mildew resistant) can be successfully blended with a stiff-strawed component (Blueboy, Potomac), and that the stiff-strawed component will help the blend remain standing until maturity.

Table 4. Mean lodgin score of wheat blends and cultivars for 1979 wheat blend experiment at Clarksville, Maryland.

Entry	Lodging score %	
Blueboy (B)	1.2	e*
Centurk (C)	90.0	a b
Holley (H)	98.8	a
Potomac (P)	25.0	c d e
B:C:H:P	23.8	c d e
B:C:H	40.0	c
B:C:P	20.0	c d e
B:H:P	8.8	d e
C:H:P	68.8	b
B:C	21.2	c d e
B:H	15.0	c d e
B:P	3.8	d e
C:H	88.8	a b
C:P	70.0	b
H:P	27.5	c d

* Means followed by the same letter are not significantly different (p=.05) by Duncan's Multiple Range Test.

Plant Height

The data for plant height are reported in Table 5. In two cases, blends (B:C:H:P and C:P) containing the tallest cultivar (Potomac) were significantly shorter than Potomac in a pure stand. However, in most other blends (B:C:H, B:C:P, B:H:P, C:H:P, B:C, C:H), the blend was significantly taller than at least one of its components in a pure stand (usually Centurk, the shortest component). This suggests that competitive effects in the blend populations may lead to etiolation of shorter members of the blend. Although this could result in increased problems with standability, this did not seem to be the case based on the interpretation of the lodging data above.

Table 5. Mean height score of wheat blends and cultivars for 1979 wheat blend experiment at Clarksville, Maryland.

Entry	Height cm	
Blueboy (B)	107.3	d e*
Centurk (C)	104.1	e
Holley (H)	112.4	a b c d
Potomac (P)	114.9	a
B:C:H:P	108.0	c d e
B:C:H	111.9	a b c d
B:C:P	111.9	a b c d
B:H:P	113.7	a b
C:H:P	112.4	a b c d
B:C	110.5	a b c d
B:H	109.2	b c d e
B:P	109.9	a b c d
C:H	113.0	a b c
C:P	109.2	b c d e
H:P	109.9	a b c d

* Means followed by the same letter are not significantly different (p=.05) by Duncan's Multiple Range Test.

Winter Survival

Winter survival data are summarized in Table 6. The poorest cultivar in terms of hardiness was Holley. However, six blends (B:C:H:P, B:C:H, B:H, C:H, B:H:P, C:H:P) of the seven which included Holley had significantly better winter survival than Holley in a pure stand. The pattern is again repeated: a poor cultivar with respect to a particular trait is masked in a blend, and can be successfully grown where it could not otherwise be grown in a pure stand.

Table 6. Mean winter survival scores of wheat blends and cultivars for 1979 wheat blend experiment at Clarksville, Maryland.

Entry	Winter Survival %	
Blueboy (B)	93.8	a b c*
Centurk (C)	97.5	a
Holley (H)	76.2	d
Potomac (P)	88.8	a b c
B:C:H:P	87.5	b c
B:C:H	97.0	a b c
B:C:P	91.2	a b c
B:H:P	87.5	b c
C:H:P	88.8	a b c
B:C	96.2	a b
B:H	86.2	c
B:P	92.5	a b c
C:H	93.8	a b c
C:P	91.2	a b c
H:P	77.5	d

* Means followed by the same letter are not significantly different (p=.05) by Duncan's Multiple Range Test.

Powdery Mildew

Powdery mildew (*Erysiphe graminis*) is the major disease problem on wheat in Maryland. Two of the cultivars in our study (Holley, Potomac) are resistant to the disease, and Centurk is only of intermediate susceptibility although its mildew score (Table 7) does not differ significantly from Holley or Potomac. Blueboy, however, is completely susceptible to the disease. In our study, we observed that in three blends (B:C:H, B:C:P, B:H:P) including Blueboy as one component, the occurrence of powdery mildew was significantly less than that for Blueboy in a pure stand. For the remaining blends in which Blueboy was a component, the incidence of powdery mildew is equivalent to that for Blueboy in a pure stand, even when resistant components such as Holley and Potomac are present. It appears that disease epiphytotics can be impeded by production of wheat blends, but that the blend composition will need to be carefully tested to realize this potential.

Grain Protein

Protein composition of the blends and cultivars in the study is summarized in Table 8. Centurk and Holley have significantly higher protein percentages than do Potomac and Blueboy. Six blends (B:C:H:P, B:C:H, B:H:P, C:H:P, B:H, H:P) of the seven containing Holley and five blends (B:C:H:P, B:C:H:, B:C:P, C:H:P, B:C) of the seven containing Centurk have significantly lower protein content than their high protein component. Since low protein is desirable in soft wheats these data suggest that high protein lines included in a blend will not diminish flour quality. In the case of Centurk, a hard wheat is being hidden in a blend with soft wheats.

Table 7. Mean powdery mildew scores of wheat blends and cultivars for 1979 wheat blend experiment at Clarksville, Maryland.

Entry	Powdery Mildew % leaf infection	
Blueboy (B)	27.5	a b
Centurk (C)	2.8	c d
Holley (H)	0.2	d
Potomac (P)	0.0	d
B:C:H:P	17.5	a b
B:C:H	10.0	b c d
B:C:P	14.0	b c
B:H:P	10.2	b c d
C:H:P	1.8	c d
B:C	16.3	a b
B:H	21.2	a b
B:P	22.5	a b
C:H	1.3	c d
C:P	0.8	d
H:P	0.2	d

* Means followed by the same letter are not significantly different (p=.05) by Duncan's Multiple Range Test.

Table 8. Mean grain protein content of wheat blends and cultivars in the 1979 wheat blend experiment at Clarksville, Maryland.

Entry	Protein %	
Blueboy (B)	10.6	c*
Centurk (C)	13.4	a
Holley	14.0	a
Potomac (P)	11.0	b c
B:C:H:P	11.0	b c
B:C:H	11.4	b c
B:C:P	11.4	b c
B:H:P	10.5	c
C:H:P	12.0	b
B:C	11.3	b c
B:H	11.2	b c
B:P	11.0	b c
C:H	13.8	a
C:P	13.2	a
H:P	11.5	b c

* Means followed by the same letter are not significantly different (p=.05) by Duncan's Multiple Range Test.

Milling and Baking Quality

The results of an analytical procedure to evaluate milling and baking quality of the grain samples from the sudy are summarized in Table 9. In general, the quality score of the blends was

approximately what would be expected from knowledge of the quality of components in pure stands. Only for the blends B:H:P, B:H:, and H:P did the data suggest a possible improvement in quality over what would have been expected based on the pure stand data alone. It does not appear from these data that milling and baking quality of poor quality wheats can be easily improved by blending good quality wheats with them. This differs from the observation of Ciha and Rubenthaler (1979) who noted that milling and baking quality of a mixture of wheat was satisfactory when as little as 25% of the blend was a good quality wheat.

Table 9. Mean quality score of wheat blends and cultivars in the 1979 wheat blend experiment at Clarksville, Maryland.

Entry	Quality Score+	
	Mean %	Expected %
Blueboy (B)	100	-
Centurk (C)	52.4	-
Holley (H)	71.5	-
Potomac (P)	83.8	-
B:C:H:P	75.3	76.9
B:C:H	69.6	74.6
B:C:P	73.9	78.7
B:H:P	90.8	85.1
C:H:P	65.4	69.2
B:C	71.1	76.2
B:H	88.3	85.8
B:P	90.1	91.9
C:H	55.7	62.0
C:P	54.9	68.1
H:P	82.9	77.7

+Quality score is based on an analytical technique developed by the Soft Wheat Quality Laboratory in Wooster, Ohio. The score is based on a composite of scores from three tests that estimate baking quality of flour derived from the grain samples submitted. The scoring procedure relates all samples to a reference sample of known good quality (Score = 100%), and in this case Blueboy. The expected score is the mean of the components of each blend, assuming that each cultivar contributes equally to the blend of which it is a component.

Conclusions

The preliminary data from our study are supportive of other studies suggesting advantages for crop production in blends. We have empirically identified possible advantages in certain blends relative to component lines for yield, test weight, lodging resistance, winter survival, the occurrence of powdery mildew, and protein content. The data for plant height and milling/baking quality do not suggest specific advantages for blends compared to pure stands of the components. Our data are not sufficient at this point for measuring stability, which is probably the single

greatest advantage for blends, and of particular value in unpredictable environments. However, the results are encouraging, and the study is continuing.

Summary

Wheat production in the developing world is characterized by unpredictability in management, environment, and production resources. Consequently, production strategies (especially the use of genetically uniform pure lines) that may be suitable for the needs of the developed world do not necessarily fit well with the needs and realities that exist in the remainder of the wheat producing regions. Alternative production strategies are available that can buffer against environmental uncertainties by diversifying the crop. These strategies can reduce the risk of genetic uniformity for small farmers while still permitting them to take advantage of the improved germ plasm available. Examples of such strategies include forms of multiple cropping, crop rotation, and mixtures or blends. This paper focuses on the specific potential and theoretical advantages available to farmers through the use of blended populations of self-pollinating crops such as wheat. The preliminary results of our wheat blend study are also summarized.

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References

Allard, R.W. 1961. Relationship between genetic diversity and consistency of performance in different environments. Crop Sci. 1:127-133.

American Society of Agronomy. 1976. Multiple Cropping. Madison, Wisconsin, p. 1-10.

Blijenburg, J.G. and J. Sneep. 1975. Natural selection in a mixture of eight barley varieties, grown in six successive years. I. Competition between the varieties. Euphytica 24:305-315.

Brim, C.A. and W.M. Schutz. 1968. Inter-genotypic competition in soybeans. II. Predicted and observed performance in multiline mixtures. Crop Sci. 8:735-739.

Browning, J.A. and K.J. Frey. 1969. Multiline cultivars. Annual Rev. of Phytopath. 7:355-382.

Browning, J.A., K.J. Frey and R.L. Grindeland. 1963. Breeding multiline oat varieties for Iowa. Iowa Farm Science. 18 (8): 5-8.

Centro Internacional de Mejoramiento de Maiz y Trigo. 1979.CIMMYT Review. p. 59-103.

Chapman, S.R., R.W. Allard and J. Adams. 1969. Yield and seed size in mixtures of wheat. Crop Sci. 9:575-576.

Ciha, A.J. and G.L. Rubenthaler. 1979. Influence of planting date and location on yield and baking quality of soft white spring wheat mixtures. Agron. Abstr. p. 99.

Clay, R.E. and R.W. Allard. 1969. Performance of homogeneous and heterogeneous barley populations. Crop Sci. 9:407-412.

Early, H.L. and C.O. Qaulset. 1971. Complementary competition in cultivated barley (Hordeum vulgare L.) Euphytica 20:400-409.

Eberhart, S.A. and G.F. Sprague. 1973. A major cereals project to improve maize, sorghum and millet production in Africa. Agron. J. 65:365-373.

Fehr, W.R. 1973. Soybean blends. Crops and Soils 26:15-17.

Frankel, O.H. 1939. Analytical yield investigations on New Zealand wheat. IV. Blending varieties of wheat. J. of Agric. Sci. 29:249-261.

Frey, K.J. and U. Maldonado. 1967. Relative productivity of homogeneous and heterogeneous oat cultivars in optimum ar sub-optimum environments. Crop Sci. 7:532-535.

Funk, C.R. and J.C. Anderson. 1964. Performance of mixtures of field corn hybrids. Crop Sci. 4:353-356.

Grafius, J.E. 1966. Rate of change of lodging resistance, yield, and test weight in varietal mixtures of oats. Crop Sci. 6: 369-370.

Harlan, J.R. 1975. Crops and Man. Am. Soc. of Agron., Madison, Wisconsin. p. 163-165.

Jennings, P.R. and R.C. Aquino. 1968. Studies on competition in rice. III. The mechanism of competition among phenotypes. Evolution. 22:529-542.

Jennings, P.R. and J. de Jesus, Jr. 1968. Studies on competition in rice. I. Competition in mixtures of varieties. Evolution 22:119-124.

Jensen, N.F. 1952. Intra-varietal diversification in oat breeding. Agron. J. 44:30-34.

Khalifa, M.A. and C.O. Qaulset. 1974. Intergenotypic competition between tall and dwarf wheats. I. In mechanical mixtures. Crop Sci. 14:795-799.

Laude, H.H. and A.F. Swanson. 1942. Natural selection in varietal mixtures of winter wheat. J. Am Soc. of Agron. 34:270-274.

Marshall, D.R. and A.H.D. Brown. 1973. Stability of performance of mixtures and multilines. Euphytica 22:405-412.

Mumaw, C.R. and C.R. Weber. 1957. Soybean varietal composites. Agron. J. 49:154-160.

National Academy of Sciences. 1972. Genetic Vulnerability of Major Crops. Washington, D.C. p. 17-22.

Palvakul, M., V.C. Finkner and D.L. Davis. 1973. Blendability of phenotypically similar and dissimilar winter barley cultivars. Agron. J. 65:74-77.

Pandey, H.N., B.S. Malik and M.V. Rao. 1979. Wheat varietal mixtures. The Ind. J. of Gen. and Plt. Breed. 38 (3):277-280.

Patterson, F.L., J.F. Schafer, R.M. Caldwell and L.E. Compton. 1963. Comparative standing ability and yield of variety blends of oats. Crop Sci. 3:558-560.

Probst, A.H. 1957. Performance of variety blends in soybeans. Agron. J. 49:148-150.

Rasmusson, D.C. 1968. Yield and stability of yield of barley populations. Crop Sci. 8:600-602.

Ross, W.M. 1965. Yield of grain sorghum hybrids alone and in blends. Crop Sci. 5:593-594.

Roy, S. D. 1960. Interaction between rice varieties. J. of Genetics. 57:137-152.

Schlehuber, A. M. and B. C. Curtis. 1961. Grain yield of four varieties of hard red winter wheat in pure stands compared to a mixture. Oklahoma Agri. Expt. Sta. Proc. Series P-394.

Schutz, W. M. and C. A. Brim. 1971. Soybean multiline mixtures. Crop Sci. 11:684-689.

Shorter, R. and D. J. Frey. 1979. Relative yields of mixtures and monocultures of oat genotypes. Crop Sci. 19:548-553.

Sij, J. W. 1975. A comparison of sybean blends with pure stands in the Texas Gulf Coast. Texas Agric. Expt. Sta. Prog. Rep. PR 3349c.

Simmonds, N. W. 1962. Variability in crop plants, its use and conservation. Biol. Rev. (Cambridge Philosophical Society) 37: 422-465.

Singh, L. N. and L. P. V. Johnson. 1969. Natural selection in a composite cross of barley. Can. J. Genet. Cytol. 11:34-42.

Stringfield, G. H. 1959. Performance of corn hybrids in mixtures. Agron. J. 51:472-473.

Suneson, C. A. 1949. Survival of four barley varieties in a mixture. Agron. J. 41:459-461.

Suneson, C. A. 1956. An evolutionary plant breeding method. Agron. J. 48:188-191.

Suneson, C. A. 1960. Genetic diversity - a protection against plant diseases and insects. Agron. J. 52:319-321.

Suneson, C. A. and G. A. Wiebe. 1942. Survival of barley and wheat varieties in mixtures. J. Am. Soc. Agron. 34:1052-1056.

Walker, A. K. and W. R. Fehr. 1978. Yield stability of soybean mixtures and multiple pure stands. Crop Sci. 18:719-723.

Warburton, C. W. 1915. Grain crop mixtures. J. of Am. Soc. of Agron. 7:20-29.

EFFECT OF SEEDING DATE AND RATE ON YIELD AND YIELD COMPONENTS OF 'STORK' WHEAT GROWN UNDER RAINFED CONDITIONS IN JORDAN

M. A. Duwayri
Jordan

Abstract

Proper date and rate of seeding are among the important factors that will contribute to yield increases of cereals in Jordan. A study was conducted during two growing seasons to determine the effect of these two factors on the yield and yield components of 'Stork' wheat.

Four dates of planting which ranged from November 11 to January 29, and four rates of seeding, namely 40, 80, 120 and 160 kg/ha, were compared in a split plot design with four replications. In both seasons delayed planting reduced grain and straw yield. This decrease in yield was associated with decrease of heads/unit area and plant height. Delayed planting resulted in the decrease of number of seeds/head and spikelet and in the weight of seeds from each head for the 1978-1979 season only.

The lowest grain and straw yields were produced by the lowest rate of seeding which also resulted in the lowest number of heads/unit area.

In the 1977-1978 season a seeding rate effect was observed for head size, number of spikelets and number of seeds/head. Interactions were detected between seeding rate and date for some of the characters under study.

Wheat occupies the largest area planted to a single crop in Jordan. The average area is estimated to be about 200,000 hectares which produces 130,000 tons at an average yield of about 650 kg/ha. This low yield is below the world average and is attributed to many factors among which are low and erratic rainfall, planting of traditional low-yielding varieties and poor cultural practices. The poor management practices include lack of use of herbicide and fertilizers, improper seeding rate and delayed planting.

The advantages of early planting to increase wheat yields are very well documented. Studies on several wheat varieties grown under different dates of seeding showed an increase of grain and straw yields by early planting. No interaction between date of seeding and variety was detected (3). In Syria, planting in the dry soil (affir) was recommended over later planting (8). The study conducted by Beutler and Foote in Eastern Oregon showed that early planting increased total dry matter of four different wheat varieties (2).

University of Jordan, Amman.

Seeding at the optimum rate is an important factor for increasing wheat yield. Studies in Ohio showed that a seeding rate of 120 kg/ha produced higher wheat yield than seeding at 90 or 105 kg/ha. Heavier seeding rates are advised when seeding is delayed beyond the normal date because the plants have less opportunity to tiller. Furthermore, the rate of seeding is generally higher for spring than for winter wheat (1).

Yields of irrigated spring wheat in Eastern Washington increased with an increase in plant population up to 270 plants/square meter (7). Spring wheat in the Western States is usually sown at a heavier rate (6). However, the optimum rate of seeding wheat in the western half of the United States is independent of date of seeding and variety (5).

The objective of the present study was to determine the effects of seeding date and rate and their interaction on yield and yield components of Stork wheat under rainfed conditions.

Materials and Methods

Two experiments were conducted in two growing seasons, namely 1977-1978 and 1978-1979 in the University farm in Jubeiha under rainfed conditions. Four dates of seeding and four rates of seeding were tested in each experiment. The dates of seeding in 1977-1978 season were DI = November 27, 1977; DII = December 31, 1977; DIII = January 14, 1978; and DIV = January 29, 1978. The dates in 1978-1979 season were DI = November 22, 1978; DII = December 18, 1978; DIII = January 1, 1978; and DIV = January 14, 1978.

The four rates of seeding in both experiments were RI = 40 kg/ha; RII = 80 kg/ha; RIII = 120 kg/ha; and RIV = 160 kg/ha. Each experiment was randomized completely in split plot design with four replications. Seeding date was the main plot and seeding rate was the subplot. The variety Stork, which is a semi-dwarf Mexican durum, was used in this study.

Each subplot consisted of six rows, 30 cm. apart and 2.5 m. long. Seeds for each row were weighed and planted by hand in well-prepared clay soil which was fertilized at planting time with N and P_2O_5 at a rate of 40 kg/ha of each.

The plots were hand-weeded. At maturity the four central rows were shortened to two meters long. Before harvest, 10 main tillers were randomly selected from each plot. These tillers were used to record plant height and the yield component characteristics. The four central rows were then harvested by sickle at 10 cm. above the soil surface. The harvest from each plot was bundled, weighed and then threshed. The seeds were cleaned and weighed and the weight of the straw was calculated by subtracting the weight of the seed from the weight of the bundle. Weights were then converted into yields on kg/ha basis. Data were statistically analyzed according to the methods described by Le Clerg *et. al.* (4).

Results and Discussion

Statistical analyses showed that interaction between seeding date and rate was found only for number of spikes/m^2 in 1977-1978 season and for grain yield and plant height in 1978-1979 season. The highest number of spikes/m^2 was obtained by the highest seeding rate planted on the earliest date, whereas yields from the lowest rate planted on the latest date were second from the bottom. The highest grain yield in the 1978-1979 season (3138 kg/ha) was produced by the highest seeding rate when planted on the earliest date. The yield from the seeding rate 40 kg/ha planted on November 22, 1978 and January 14, 1979 were 1350 and 1330 kg/ha, respectively. The average yield of the seeding rates 120 and 160 kg/ha planted on January 14, 1979 was 1822 kg/ha. Since very few interactions were found, the data are presented in Tables 1-4 on the basis of the effect of seeding rate and seeding dates.

Data presented in Table 1 show that both grain and straw yields were increased significantly by increasing the seeding rate from 40 and 80 kg/ha to 120 and 160 kg/ha in the 1977-1978 season. The increase in yield was associated with increase in number of heads/m^2. However, increasing the seeding rate caused a reduction in head length and weight which is expected since the larger number of heads causes greater competition for nutrition and light. The lowest seeding rate gave the highest number of seeds/spike and seeds/spikelet. The same pattern for seeding rate was detected in the season 1978-1979 for most of the characteristics included in the study (Table 3).

The effects of seeding date are presented in Tables 2 and 4. Early planting (November 27, 1977), after the total rains for that season amounted to 113 mm., gave 92% more grain than when wheat was planted on January 29, 1978 which is a practice followed by many farmers in Jordan. The straw yield was reduced 68% by delaying planting until January 29, 1978. The December planting in 1979 was affected by excess soil moisture which followed that date of planting and thus gave similar results to that of January 14, 1978. Delayed planting reduced number of spikes/m^2, i.e. less number of tillers and plant height which affected straw yield. Furthermore, it gave shorter heads, smaller seeds and lower spikelet fertility although these reductions were not statistically significant. The same pattern was observed in the following season although the differences were more conspicuous by being statistically significant. Both grain and straw yields were reduced by 23% and 31%, respectively, when planting was delayed to November 22 and January 14.

Results presented in Table 4 show that delaying planting from November 22, 1978 to December 18, 1978 did not decrease grain yield but increased yield slightly, which was not statistically significant. This leads to the conclusion that one cannot interpret the biological data without considering weather data. Data in Table 5 give some indications of rainfall in Jubeiha and the magnitude of the seasonal and annual fluctuations. The total rain in October and November in the 1977-1978 season was 113 mm. compared to 19 mm. for the same period in 1978. This indicates that, although we planted on November

Table 1. Effect of seeding rate (average of four seeding dates) on grain and straw yield and yield components of Stork wheat grown under rainfed conditions in Jordan in the 1977-1978 season.

Seeding rate (kg/ha)	Grain yield (kg/ha)[1/]	Straw yield (kg/ha)	Grain-straw ratio	Spikes/ m^2	Height (cm)	Length of spike (mm)	Weight of seeds/ spike(mg)	No. of spikelets/ spike	No. of seeds/ spike	No. of seeds/ spikelet	1000 seeds weight (g)
40	1397^{b}	2229^{b}	0.64	139^{c}	67	63^{a}	1468^{a}	16.1^{a}	38.4^{a}	2.41^{a}	41.5
80	1543^{b}	2511^{b}	0.61	175^{b}	68	60^{ab}	1319^{b}	15.0^{b}	34.1^{b}	2.30^{a}	41.3
120	1814^{a}	3027^{a}	0.59	237^{a}	66	57^{b}	1147^{c}	14.8^{b}	30.1^{c}	2.03^{b}	40.7
160	1896^{a}	3345^{a}	0.56	236^{a}	68	58^{b}	1289^{b}	15.2^{ab}	32.8^{bc}	2.14^{b}	40.2

[1/] Means within a column followed by the same letter are not significantly different at the 0.05 level of probability as determined by Duncan's Multiple Range test.

Table 2. Effect of seeding date (average of four seeding rates) on grain and straw yield and yield components of Stork wheat grown under rainfed conditions in Jordan in the 1977-1978 season.

Date of seeding	Grain yield (kg/ha)[1/]	Straw yield (kg/ha)	Grain-straw ratio	Spikes/ m^2	Height (cm)	Length of spike (mm)	Weight of seeds/ spike(mg)	No. of spikelets/ spike	No. of seeds/ spike	No. of seeds/ spikelet	1000 seeds weight (g)
November 27, 1977	2147^{a}	3384^{a}	0.65	229^{a}	73^{a}	62	1422	15.9	36.1	2.30	42.8
December 31, 1977	1606^{bc}	2649^{bc}	0.61	192^{bc}	68^{a}	58	1289	14.8	32.8	2.21	41.9
January 14, 1978	1778^{ab}	3063^{ab}	0.59	207^{ab}	68^{a}	60	1306	15.6	33.8	2.16	38.9
January 29, 1978	1118^{c}	2018^{c}	0.56	158^{c}	60^{b}	57	1206	14.8	32.8	2.21	40.0

[1/] Means within a column followed by the same letter are not significantly different at the 0.05 level of probability as determined by Duncan's Multiple Range Test.

Table 3. Effect of seeding rate (average of four seeding dates) on grain and straw yield and yield components of Stork wheat grown under rainfed conditions in Jordan in the 1978-1979 season.

Seeding rate (kg/ha)	Grain yield (kg/ha)[1/]	Straw yield (kg/ha)	Grain-straw ratio	Spikes/ m^2	Height (cm)	Length of spike (mm)	Weight of seeds/spike(mg)	No. of spikelets/spike	No. of seeds/spike	No. of seeds/spikelet	1000 seeds weight (g)
40	1867	3448^{b}	.55	194^{c}	78	71^{a}	1693^{a}	17.5	38.3^{a}	2.14^{a}	43.9^{a}
80	2047	4010^{a}	.51	247^{b}	78	68^{b}	1586^{ab}	16.7	36.3^{ab}	2.12^{a}	43.8^{a}
120	2116	4278^{a}	.50	279^{ab}	77	67^{bc}	1573^{ab}	16.5	35.4^{ab}	2.09^{ab}	44.6^{a}
160	1947	4204^{a}	.46	301^{a}	76	66^{c}	1324^{b}	16.3	33.2^{b}	1.96^{b}	40.8^{b}

[1/] Means within a column followed by the same letter are not significantly different at the 0.05 level of probability as determined by Duncan's Multiple Range Test.

Table 4. Effect of seeding date (average of four seeding rates) on grain and straw yield and yield components of Stork wheat grown under rainfed conditions in Jordan in the 1978-1979 season.

Seeding date	Grain yield (kg/ha)[1/]	Straw yield (kg/ha)	Grain-straw ratio	Spikes/ m^2	Height (cm)	Length of spike (mm)	Weight of seeds/spike(mg)	No. of spikelets/spike	No. of seeds/spike	No. of seeds/spikelet	1000 seeds weight (g)
November 22, 1978	2079^{ab}	4689^{a}	.45	283^{a}	85^{a}	68	1491^{b}	16.9	37.6^{ab}	2.17^{a}	42.8
December 18, 1978	2259^{a}	4076^{b}	.55	229^{c}	78^{b}	70	1827^{a}	17.0	38.0^{a}	2.18^{a}	45.8
January 1, 1978	1946^{b}	3597^{bc}	.55	254^{b}	75^{c}	67	1431^{b}	16.5	32.8^{c}	1.92^{b}	43.3
January 14, 1979	1694^{c}	3578^{c}	.48	255^{b}	70^{d}	66	1428^{b}	16.5	34.7^{bc}	2.06^{ab}	41.2

[1/] Means within a column followed by the same letter are not significantly different at the 0.05 level of probability as determined by Duncan's Multiple Range Test.

22, 1978, the seeds did not germinate and the effect was practically similar to the December planting. Furthermore, this indicates that even if sufficient rain does not fall to cause seed germination or even if the seed germinates but growth is halted for a short period, early planting during such seasons will not be inferior to delayed planting.

Table 5. Average monthly rainfall at Jubeiha for the period 1952-1962 and for the past three years, 1977-1980.

Month	Year			
	1952-1962	1977-1978	1978-1979	1979-1980
October	1.6	101.0	10.7	35.8
November	45.6	11.6	8.5	171.9
December	79.9	159.9	85.2	161.1
January	91.7	72.5	79.6	133.2
February	92.7	56.3	13.5	124.1
March	69.5	130.4	76.8	160.0
April	17.1	13.0	3.5	20.2
May	3.6	-	-	-
June	-	-	-	-
Total	401.6	544.7	277.8	806.3

Conclusion

The present study has demonstrated that increases in wheat yield could be obtained by planting Stork seeds at rates of 120 kg/ha to 160 kg/ha over lower planting at lower rates. Early and normal planting from November to December proved to be more profitable than delaying planting until late December or January. Increases in grain yield were associated with increases in straw yield which is a desirable characteristic since straw is an important feed commodity. Early seeding dates gave taller plants which again is a desirable agronomic characteristic for the semi-dwarf varieties under the Jordan conditions because it permits harvesting by combine.

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Literature Cited

1. Bayfield, E. G. 1936. The influence of climate, soil and fertilizers upon quality of soft winter wheat. Ohio Agr. Exp. Sta. Bull. 563.
2. Beutler, L. K. and W. H. Foote. 1963. Influence of date of seeding and nitrogen rates on winter wheat varieties in eastern Oregon. Agron. J. 55:4-6.
3. Duwayri, M. Effect of sowing date on yield of wheat under rainfed conditions in Jordan. (Accepted for publication in Dirasat).
4. Le Clerg, E. L., W. L. Leonard, and A. G. Clark. 1969. Field-plot Technique. Burgess Publishing Company, Minneapolis, Minnesota.
5. Martin, J. H. 1926. Factors influencing results from rate and date of seeding experiments with winter wheat in the western United States. J. Am. Soc. Agron. 18:193-225.
6. Salmon, S. C., D. R. Mathews and R. W. Leukel. 1953. A half century of wheat improvement in the United States. In Advances in Agronomy vol. 5:1-15, Academic Press, New York.
7. Woodward, R. W. 1956. The effect of rate and date of seeding small grains on yield. Agron. J. 18:160-162.
8. Quheiwi, J. 1977. A study on the effect of seeding date on three Syrian wheat varieties in an agriculture center under rainfed conditions. A bulletin by the Center for the Studies of Arid Zones and Drylands (ACSAD). 24 pp. (in Arabic)

MODELING GRAIN PRODUCTION OF WHEAT UNDER CONDITIONS OF LIMITING WATER SUPPLY: A CASE STUDY.

H. van Keulen
The Netherlands

The basis for the calculation is the photosynthesis light response curve of individual leaves, characterized by an initial light use efficiency at low light intensities and a maximum level, where CO_2 diffusion is the limiting factor. When experimentally-determined relations of this type are available in combination with the spatial arrangement of the leaves in the canopy and their optical properties, the gross rate of CO_2 assimilation may be obtained at any moment from the level of irradiance. Integration of these values over the day yields the daily potential gross CO_2-assimilation. Values of this variable have been tabulated by Goudriaan and Van Laar (1978) for different saturation levels as a function of latitude and time of the year. They hold for closed green crop surfaces (where all irradiance is intercepted). In the calculation scheme, incomplete cover is accounted for by assuming exponential extinction in the canopy with an extinction coefficient of 0.5. For any given situation, gross canopy photosynthesis can be derived in this way. Potential canopy photosynthesis may not be achieved due to insufficient moisture supply. To account for water shortage, a simple soil water balance is administered in which the available soil moisture, that is the amount of soil water between "field capacity" and "wilting point", is tracked.

Available water may increase by rain or by irrigation and decreases by soil evaporation and transpiration by the canopy. The latter two terms are combined into total evapotransporation. The basic assumption is that, when sufficient soil moisture is available, total evaporative demand will be satisfied either through the plant or from the soil surface. That is an oversimplification since, especially at incomplete soil cover, the top soil may be dry, thus effectively preventing direct surface evaporation, while moisture still remains available at greater depth. In the present simplified approach no attempt has been made to incorporate a more sophisticated assumption.

It appeared necessary to take the rooting depth into account, since soil moisture stored at greater depth may not be available for plant uptake in the early stages of the growing season. It is assumed, therefore, that the plant roots extend vertically at a rate of 1.2 cm per day, thus gradually increasing the availability of soil moisture at greater depth.

The evaporative demand (potential evaportranspiration) is obtained from the Penman formula using the coefficients originally defined by the author (Penman, 1948).

Centre for Agrobiological Research, Wageningen

When the total amount of available moisture in the soil, augmented by rain or irrigation in the relevant period, is insufficient to satisfy the evaporative demand, actual evapotranspiration is equal to the sum of these terms. Actual gross canopy photosynthesis is then calculated under the assumption that a direct proportionality exists between the ratio of actual and potential evaportranspiration and that of actual and potential gross photosynthesis. Any possible modifications in water use efficiency are thus disregarded in this way.

Part of the carbon fixed in the photosynthetic process is respired to provide energy for biological functioning of the plant. Two main components are distinguished in the scheme: maintenance respiration which is proportional to the amount of dry matter present in the field. Temperature and chemical composition of the material are influencing the maintenance respiration, but in the present simplified approach these factors have been ignored and the maintenance requirement is assumed to be 0.02 kg kg^{-1} (dry matter) before anthesis and 0.015 after that time.

Growth respiration is taken into account by means of a conversion efficiency of primary photosynthates into structural plant material. Here again the chemical composition of the material formed is the major determinant of the overall efficiency, but an average value of 0.7 kg (dry matter) kg^{-1} (photosynthates) is used for the vegetative plant material and 0.8 for the grains having on the average a somewhat lower protein content.

The total amount of dry matter produced during one period is divided between leaves, stems (including the leaf sheaths) and grains. The partitioning coefficients vary with the phenological stage of the canopy. In the first one third of the growth period only leaves are formed. From that moment until anthesis the newly formed material is divided equally between leaves and stems whereas after anthesis all current photosynthates are used for grain filling. The green leaf area of the canopy is obtained from the weight of the leaves assuming a specific leaf area of 15 m^2 kg^{-1} dry matter.

The leaves of a plant have a limited life span, hence after some time they die off. This process is ignored in the early stages of crop development but after anthesis a constant relative death rate, due to senescence, of 0.03 day^{-1} is assumed. Application of this value reduces the green leaf area by a factor of two in about three weeks. When water shortage occurs during that period accelerated senescence is assumed, the relative death rate increasing in proportion to the transpiration deficit.

The phenological development of the crop is introduced in the present example as a forcing function, the onset of stem formation and the moment of anthesis being taken from field observations. For the purpose of comparing different sowing dates or various

years at the same site it should be possible to define these events on the basis of accumulated heat sums, as was done for bunded rice (van Keulen, 1976).

The calculation scheme is executed for time intervals of ten days. In the above-mentioned example of rice it was shown that the results are not very sensitive to the magnitude of the time-interval.

The scheme outlined in the previous section was tested on data collected near Sde Boker in the Negev Desert of Israel, (Long. 34° 41' E., Lat. 30°51' N) in the framework of a joint Dutch-Israeli research project on dry land agriculture. Annual rainfall in the area is too low (long-term average 92 mm yr) for arable cropping which can only be practiced with irrigation. Different irrigation treatments were imposed so that water stress in the canopy developed at different stages of development. Detailed information on the experiments and its results will be published elsewhere (Hochman and van Keulen, in prep.).

Measured and calculated dry matter accumulation for three irrigation regimes are given in Figure 1.

For the non-stressed treatment, the calculated curve coincides closely with the measured one until about 120 days after emergence, well into the grain filling stage. Towards the end of the growing period the calculated growth rate is about 10% below the measured one. This could be due to the fact that leaf senescence is overestimated in the calculation scheme, since the crop, which was also well supplied with nutrients, showed a healthy appearance for an extended period. This cannot be verified with experimental data, however, since determination of green leaf area was discontinued at anthesis.

The calculated grain yield (Table 1) is somewhat lower than the measured value, but is situated within the 5% accuracy limit. In the present formulation no contribution of pre-anthesis photosynthesis to grain yield is taken into account, but that is probably counterbalanced by the fact that in reality a small proportion of post-anthesis assimilation is required for growth of vegetative tissue (e.g. roots). In treatment 2 waterstress was allowed to build up in the late vegetative stage between day 60 and 90 after emergence. Again the calculated curve agrees very well (Figure 1) with the measured one. These results indicate that the assumption that water use and dry matter production are proportional holds also in this situation. Any change in water use efficiency under water stress cannot be detected from the experimental data. The lower grain yield for this treatment can be explained fully by the accelerated senescence of leaves during stress resulting in a smaller green leaf area and, hence, less intercepted irradiance during the reproductive stage.

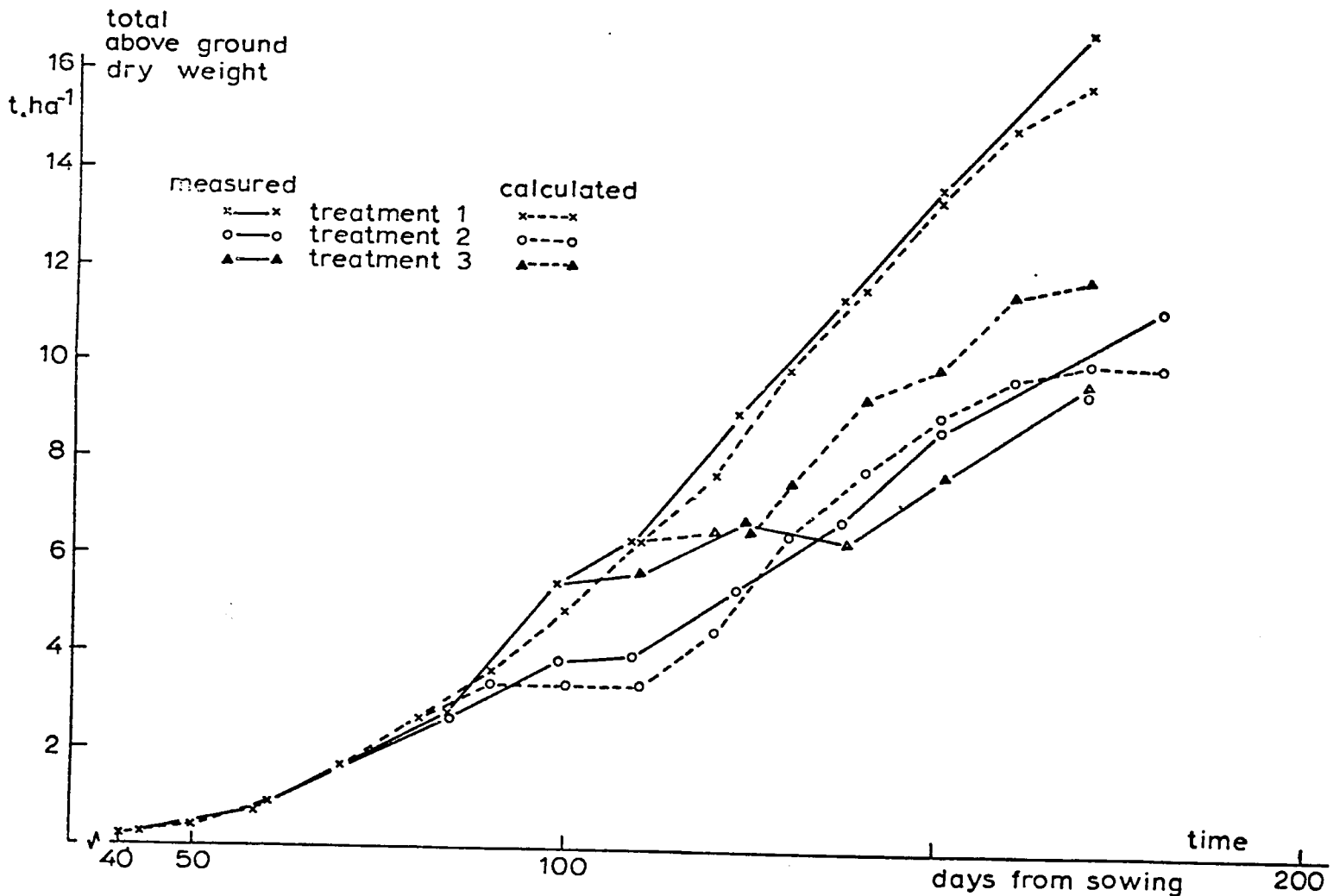

Figure 1. Course of measured and calculated DM growth for three irrigation treatments.

Table 1. Calculated and measured grain yield (kg ha^{-1}).

Treatment	Measured	Calculated
1	7790	8081
2	5590	5580
3	4980	5072

The results of treatment 3, where moisture stress developed between day 90 and day 110 coinciding with period of flowering and pollination, are contradictory to the previous one. The calculated growth rates after restoration of soil moisture are far higher than the measured ones, especially in the first ten-day period. The reason for this discrepancy is not clear, although one could speculate that the stress treatment not only resulted in accelerated senescence of leaves but also affected the photosynthetic capacity of the remaining green leaf area. A similar phenomenon of a lag in the recovery after water stress was observed in a natural pasture situated in the same environment (van Keulen et al., 1980). This seems a more likely explanation than one of sink-size limiting the growth rate of the grains, since after day 120 the measured growth rate is practically identical to the calculated one.

The calculated and measured grain yields are hardly different, which is unexpected in view of the difference in total dry matter accumulation. In this case post-anthesis assimilates must have supplied a substantially larger part of the final grain weight in reality. It could be speculated that most of the photosynthates produced during the stress period could not be used for growth, but were stored and available for translocation to the grain.

In Table 2 some variables pertaining to the calculated water balance are given. The partitioning between transpiration and evaporation is calculated under the assumption that in each period the ratio between the two terms is equal to the ratio of absorbed and transmitted radiation. The results show that in all cases direct soil surface evaporation ranging between 20 and 36% of the total evapotranspiration constitutes a major source of water loss under these semi-arid conditions. The transpiration coefficients of slightly over 200 kg H_2O kg^{-1} (dry matter) are virtually identical for all treatments. These values are substantially lower than the ones reported for other C3 species growing in the same environment (van Keulen, 1975). This observation suggests that the wheat crop under consideration must have shown stomatal regulation through the internal CO_2-concentration for at least part of its growth period.

Table 2. Calculated values of evapotranspiration (ET), evaporation (E), transpiration (T), and transpiration coefficient (TRC = T/DM).

Treatment	ET mm	E mm	T mm	TRC kg H_2O kg^{-1} (DM)
1	421	85	336	211
2	347	126	221	218
3	332	88	244	211

The results presented here show that a simple method, based on available physiological and physical knowledge, may be used to calculate yields under varying climatic conditions. Combination with a simple waterbalance provides an opportunity to take into account periods of suboptimum water supply leading to reduced transpiration and lower growth rates. It seems, however, that when periods of severe stress are encounted, reduced transpiration and stress-induced leaf death cannot account for all the observed effects. A more extensive testing in different situations is necessary, however, to arrive at firm conclusions in this respect.

This simulation approach will be improved by including the plant and soil processes which are involved in the crop response to nitrogen supply. Further study is required on the nature of interactions between water use, nutrient uptake and root activity, especially during the grain-filling period.

References

Goudriaan, J. and H. H. van Laar. 1978. Relations between leaf resistance, CO_2 concentration and CO_2 assimilation in maize, beans, lalang grass and sunflower. Photosynthetica 12:241-249.

Hochman, Z. and H. van Keulen. (in prep.)

van Keulen, H. 1975. Simulation of water use and herbage growth in arid regions. Simulation Monographs, PUDOC, Wageningen. 184 pp.

van Keulen, H. 1976. A calculation method for potential rice production. Contr. Centr. Res. Inst. Agric. Bogor. 21. 26 pp.

van Keulen, H., N. G. Seligman, and R. W. Benjamin. 1980. Simulation of water use and herbage growth in arid regions. A reevaluation and further development of the model arid crop. Agric. Systems (in press).

YIELD, YIELD COMPONENTS, AND QUALITY OF FOREIGN AND NATIVE WHEAT VARIETIES GROWN AT ERZURUM, TURKEY

C. Koycu and B. Yilmaz
Turkey

Abstract

Experiments were conducted to study the yield, yield components and some quality characters of 30 foreign and native common winter wheat cultivars at the Experimental Farm of Ataturk University, Erzurum, Turkey, from 1975 to 1977. A complete randomized block design with four replications was employed.

Significant varietal differences were found in all of the characters studied. The characters under consideration, except the crude protein content of the kernel, differed significantly in each of the years. Year X variety interactions were found to be significant in most cases.

Grain yields of the common winter wheat varieties varied from 189.0 to 453.3 kg per dekar. The foreign varieties, and F9M1B162, a progeny of Yayla-305, were found to be the highest in grain yield.

Significant positive correlations were found between grain yield and the following characters: total yield, grain yield index, number of kernels per spike, grain yield per spike, hectoliter weight, crude protein yield of grain, total protein yield and Zeleny sedimentation test value. The correlation between plant height, percent crude protein of kernel, percent crude protein of straw and grain yield were negative and significant.

Today many research centers are working on breeding new varieties. The goals of breeding which are resistance to diseases and ecological factors, high yield, and good quality are carefully evaluated and satisfactory crosses are released to the farmers. Important for the breeder is a knowledge of the relationships between yield and other plant characters. Research workers agree that variety performance is complex and selection criteria for semi-arid regions could not be expected to be very simple (Schmidt, 1975).

Yield is mainly correlated with number of heads per m^2, number of seeds per head, number of heads per plant, kernel weight, and head length (Engledow and Wadham, 1923; Grafius, 1956, 1964; Sing and Pratap, 1967; Jain and Khan, 1969). Many workers' studies have taken into account physiological and morphological (physio-

Ataturk University, Erzurum

morphological) traits which play an important role in total yield (Watson, 1962; Thorne, 1966; Voldeng and Simpson, 1967; Simpson, 1968; Lupton, 1969; Smocek, 1969; Hsu and Walton, 1970, 1971; Genc, 1972).

Materials and Methods

The research station of the Experimental Institute is a section of the Ataturk University of Agriculture Faculty in Erzurum. It cooperates with the Eastern Anatolia Agr. Res. Inst. in Erzurum. The winters are cold and snowy. *Triticum aestivum* L. is widely grown on the land on more than 1,260,000 ha in the Eastern Anatolia.

Some climatic conditions during two years of trials in 1975-76 and 1976-77 and the long-time average (1929-1977) for temperature, rainfall, and relative humidity from September to August are given in Table 1. During two years of this work, the general climatic conditions were favorable, especially rainfall which averaged 426.7 mm.

The materials can be separated into three groups: 1) foreign origin varieties; 2) cultivars coming from Eastern Anatolia's Villages population selected from Villages Screening Nursery; and, 3) Turkish Country-Wide Leadership cross material comprised of advanced lines selected in Erzurum from segregating material.

The soil, where the trial was made is Palandoken silty loam of good fertility and was previously fallow. The seeding date was September 8 in both years. Emergence was regular.

Fertilizers used were 60 kg/ha of N (1/2 with seeding, 1/2 at boot stage), 60 kg/ha of P_2O_5 (with seeding). K_2O was not used, it was sufficient in the soil.

The traits and their scores:

1. Yield of grain: determined from the four central rows of each plot (harvested area = 6.12 m^2), corrected to 14% moisture and reported in kg per hectare.

2. Straw yield: determined from same area and reported in kg per hectare.

3. Total yield: grain yield + straw yield, kg per hectare.

4. Grain yield index: calculated from grain yield/total yield.

5. Number of fertile spikes per m^2: determined from plants in border rows after maturity and calculated on basis of number/m^2.

6. Number of spikelets per spike: counted in the 20 heads.

7. Number of kernels per spike: counted from same 20 heads.

8. Seed weight per head: average weight of grain from 20 heads.

9. 1000-kernel weight: samples taken from grain harvested from each plot and weight determinations made.

10. Hectoliter weight: based on grain samples taken from each plot.

11. Plant height: measured from soil surface to the head (cm).

12. Terminal internode length: average measured length of terminal internodes of 20 plants per plot (cm).

13. Flag leaf length: average from measuring 20 culms (cm).

14. Flag leaf width: average from measuring 20 culms at the widest section of flag leaf (cm).

15. Head length: average from measuring heads on 20 plants (cm).

16. Number of tillers per plant: average number of tillers per plant.

17. Crude protein content of seed: amount of N based on macro Kjeldahl determinations multiplied by 5.70.

18. Kernel crude protein yield: calculated from the crude protein content of kernel.

19. Crude protein content of straw: amount of N based on Kjeldahl determinations multiplied by 6.25.

20. Crude protein yield of straw: calculated from crude protein content of straw.

21. Total crude protein yield: sum of kernel crude protein yield + crude protein yield of straw.

22. Zeleny sedimentation test value: Zeleny sedimentation test method was utilized, values corrected to 14% moisture.

Statistical treatment.--All data collected and averaged for each variety over two years.

Statistical treatment of data included determination of the mean, standard error, coefficient of variation, least significant difference at 0.05 and 0.01, and standard deviation (Table 2).

Simple correlations among the characters measured were calculated.

Results and Discussion

The main goal of this study was to compare native varieties, advanced lines, and foreign varieties which are high yielders under Eastern Anatolia ecological conditions.

The results of the study can be summarized as follows:

Significant varietal differences were found in all of the characters studied. The experimental years differed from each other, significantly in the characters under consideration, except crude protein content of kernel (Table 1). Year X variety interactions were significant in most cases (Table 3).

Grain yields of the common winter wheat varieties varied from 1890 to 4533 kg per hectare (Table 2). The foreign varieties and F9M1B162 (a progeny of Yayla-305) were the highest in grain yield.

Significant positive correlations were found between grain yield and total yield, grain yield index, number of the kernels per spike, grain yield per spike, hectoliter weight, crude protein yield of grain, total crude protein yield, and Zeleny sedimentation test value (Table 4). The correlations between plant height and percent crude protein of kernel, percent crude protein of straw, and grain yield were negative and significant.

Straw yield varied from 8067 to 12,648 kg per hectare depending upon variety. The native varieties were highest in this respect. Among these were Village-8 (registration number), F9M1B162, and Village-2. Total yield, number of fertile spikes, plant height, crude protein content of straw, total crude protein yield and Zeleny sedimentation test value were significantly and positively correlated with straw yield.

Total yield (grain + straw) ranged from 10,810-15,644 kg per hectare. F9M1B162 and Village-8 were the highest varieties in this respect. Significant positive correlations were found between hectoliter weight, crude protein yield of kernel, total crude protein yield, Zeleny sedimentation test value and total yield.

The grain yield index varied from 17.1-30.8% depending upon the variety. Besides foreign cultivars, F9M1B162 and some other native varieties were found to be the highest in grain yield index. Grain yield index was significantly and positively correlated with number of kernels per spike, hectoliter weight, crude protein yield of grain, total crude protein yield, and Zeleny sedimentation test value. On the other hand, it was significantly and negatively correlated with percent and yield of crude protein of the straw.

Number of fertile spikes per m^2 of the cultivars studied ranged from 742.0 to 1380.5 on the average. The varieties with the highest number of fertile spikes per square meter were B-2289,

Table 1. Precipitation, temperature and relative humidity during two crop years at Erzurum.

Year	Month												Total or Average
	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	
	Rainfall, mm												
1975-76	38.0	31.5	17.7	11.9	55.7	33.1	13.1	82.0	47.3	77.0	52.6	0.2	460.1
1976-77	14.7	37.4	24.5	32.1	82.9	76.7	69.4	55.7	59.5	56.4	45.9	38.4	593.6
Average	26.3	34.5	21.1	22.0	69.3	54.9	41.2	68.8	53.4	66.7	49.2	19.3	526.7
1929-77	27.4	45.7	35.8	23.0	25.1	29.2	38.0	52.7	73.5	55.1	30.1	18.9	454.5
	Average temperature, C°												
1975-76	14.0	6.4	0.7	-7.4	-9.8	-12.5	-4.2	4.3	9.4	14.7	17.2	20.8	4.6
1976-77	14.4	8.9	3.1	-3.5	-12.0	-3.1	0.2	6.6	10.7	15.0	18.7	19.9	6.6
Average	14.2	7.6	1.9	-5.4	-10.9	-7.8	-2.0	5.4	10.0	14.9	18.0	20.4	5.6
1929-77	14.9	8.6	1.7	-5.3	-8.6	-7.2	-2.9	5.2	10.9	15.0	19.1	19.6	5.9
	Relative humidity, %												
1975-76	51.6	59.7	69.7	72.9	79.8	78.5	82.0	70.4	63.3	58.7	51.4	42.4	65.0
1976-77	49.1	67.3	63.5	80.9	82.9	76.7	69.4	55.7	59.5	56.4	45.9	38.4	66.3
Average	50.3	63.5	66.6	76.9	81.4	77.6	75.7	63.0	61.4	57.6	48.6	40.4	65.6
1929-77	48.9	60.1	71.2	74.9	76.0	75.0	73.7	64.9	60.1	56.4	49.8	46.2	63.1

Table 2. Yield, yield components and protein for varieties in two crop seasons at Erzurum (1975-76, 1976-77).

Variety or line	Grain yield kg/ha	Straw yield kg/ha	Total yield kg/ha	Grain yield index	No. of fert. spike per m²	Spikelets per spike	Kernels per spike	Grain yield per spike g	1000 kernel weight g	Hectoliter weight	Plant height cm	Terminal internode length cm	Flag leaf length cm	Flag leaf width cm	Spike length cm	No. of tillers per plant	Crude protein content of kernel %	Kernel crude protein yield kg/ha	Protein cont. of straw %	Straw protein yield kg/ha	Total crude protein yield kg/ha	Zeleny sed. test value
F9M13162	4533	11110	15644	29.2	1284	14.5	27.1	0.84	31.3	79.5	113	48	16	1.0	7.3	4.2	14.6	670	3.4	369	1039	46.0
B-2232	4211	10605	14816	28.6	1052	13.8	27.3	1.10	39.4	80.4	105	45	18	1.1	8.0	2.7	14.8	629	3.5	371	1000	30.8
Bezostaya	4185	10170	14355	29.2	850	16.1	31.5	1.37	45.4	82.0	93	41	21	1.1	9.3	2.5	15.4	639	3.7	375	1014	44.6
Nugaines	4116	9527	13649	30.8	742	16.7	34.2	1.14	37.7	72.5	67	26	18	1.1	7.6	2.7	14.8	617	4.3	427	1044	39.1
Karrier	3818	10511	14329	26.7	1267	14.0	27.4	0.77	30.0	78.7	111	49	19	1.1	7.2	[illegible]	14.8	585	4.1	394	969	45.5
F9M1A112	3799	11444	15243	24.9	1100	13.2	23.0	0.75	31.5	80.3	[illegible]	48	15	1.0	6.7	3.6	15.3	580	3.7	422	1001	42.0
F9M26177	3737	9995	13732	27.5	1073	15.4	34.2	1.14	31.3	78.7	105	48	17	1.2	8.8	3.9	16.6	622	3.9	395	1021	26.9
B-2973	3421	8067	11488	29.4	873	16.3	39.7	1.54	38.0	74.1	88	33	21	1.5	8.4	3.0	13.6	465	3.7	286	751	14.8
Village-2	3390	11209	14599	23.7	1244	13.6	21.9	0.70	31.5	79.3	104	46	18	1.0	7.3	3.4	17.2	585	4.0	437	1022	38.9
F9M2A288	3258	10161	13419	24.3	1074	14.9	30.7	0.93	31.0	78.5	111	47	20	1.1	9.2	3.6	15.6	515	4.1	411	929	33.3
B-2541	3150	11515	14665	21.6	919	14.1	28.0	1.11	38.9	77.2	114	45	19	1.0	9.1	2.2	15.7	496	4.1	447	943	24.7
Tophos	3079	9573	12652	24.0	1060	13.4	23.2	1.01	43.3	79.5	117	50	19	1.1	10.1	3.3	15.9	484	3.6	340	823	13.2
Village-8	2933	12648	15621	19.3	1171	13.8	24.0	0.80	34.0	75.4	124	52	20	1.1	8.6	4.0	16.9	506	4.2	534	1040	29.4
Village-3	2962	10070	13032	22.5	1141	15.0	23.7	0.82	36.2	75.8	119	49	16	1.1	6.5	3.2	15.7	471	4.6	449	920	15.8
Yonusak	2945	8676	11621	25.3	970	14.0	23.9	0.89	37.7	77.8	105	41	18	1.0	9.0	3.0	15.2	469	5.0	426	895	24.2
B-434	2882	9829	12711	23.5	1136	12.7	24.8	0.82	33.2	77.0	111	53	21	1.0	8.0	3.1	14.6	415	3.0	321	736	26.4
B-2551	2826	11195	14021	19.7	1197	14.0	25.5	0.97	37.0	78.3	108	38	22	1.0	9.1	2.6	16.0	452	4.3	472	923	25.6
Village-7	2761	8794	11555	23.2	1100	14.1	24.4	0.85	35.1	76.8	108	44	19	1.0	6.5	3.5	16.3	450	4.0	369	819	13.1
Village-5	2700	8944	11644	22.7	1055	13.2	18.7	0.67	34.7	76.5	105	44	17	1.3	9.3	3.3	16.3	441	4.4	394	835	20.3
Odessskaya 51	2656	10450	13106	20.4	850	17.8	35.0	1.35	42.3	72.3	115	46	19	1.1	10.1	2.6	14.3	379	5.2	542	921	21.7
B-2289	2633	10377	13010	20.4	1350	13.4	24.7	0.98	39.0	77.8	102	41	19	1.1	9.4	3.9	15.5	412	3.6	360	771	11.6
Village-6	2632	10875	13507	19.0	1058	13.8	21.0	0.68	37.1	70.6	108	49	19	1.1	10.6	2.9	13.4	346	4.6	501	847	17.4
B-3079	2621	10978	13599	19.5	1104	12.3	23.4	0.75	31.0	78.3	121	43	19	1.0	8.3	2.9	17.1	451	4.2	453	905	54.0
F-2065	2619	10804	13423	19.1	1067	14.6	24.9	0.75	38.1	77.2	109	46	19	1.0	9.4	3.1	14.7	376	6.2	662	1038	16.1
B-3667	2457	10364	12821	19.3	1047	15.2	30.1	0.79	25.8	75.8	124	49	20	1.1	9.0	3.0	16.4	407	3.5	361	768	25.9
Yerla-305	2450	11064	13514	17.8	1329	14.3	23.3	0.75	31.9	74.9	105	41	18	1.0	9.8	4.6	16.6	407	4.7	512	919	24.2
Village-1	2360	9772	12132	19.6	1350	14.7	27.1	0.69	26.3	78.3	109	46	17	1.0	8.2	3.4	16.7	391	4.0	390	781	23.1
Village-4	2354	8845	11199	20.3	1155	13.0	20.7	0.71	34.2	71.4	101	43	20	1.1	9.2	3.4	16.1	373	4.4	363	737	16.1
B-3776	2225	10063	12288	18.4	1025	14.9	24.8	0.75	34.5	77.2	118	46	17	1.1	8.6	3.0	16.4	364	3.9	404	769	14.0
B-2143	1891	8919	10810	17.1	872	12.6	22.0	0.62	32.3	71.0	105	46	16	1.1	9.4	2.7	16.0	303	4.2	377	680	24.0
Mean	3055	10219	13273	22.9	1093	14.3	26.3	0.909	34.99	76.75	107.8	44.7	18.4	1.08	8.60	3.22	15.69	476.8	4.12	418.6	895.3	26.99
LSD 0.05	44	163	191	2.4	258	1.0	4.0	0.194	1.52	1.08	6.3	4.1	1.7	0.10	0.74	0.94	0.92	71.4	1.18	75.2	127.0	4.04
LSD 0.01	62	231	270	3.4	364	1.4	5.6	0.273	2.52	1.52	8.9	5.7	2.4	0.14	1.05	1.33	1.22	100.6	1.57	106.0	179.0	5.40
C.V. %	16	17	16	11.5	26	7.6	16.4	23.06	5.54	1.53	6.3	9.8	10.0	10.34	9.35	31.74	5.15	16.2	20.22	19.4	15.4	10.58
St. dev.	48	177	208	2.6	280	1.1	4.3	0.210	1.94	1.17	6.8	4.4	1.9	0.11	0.80	1.02	0.81	77.2	0.83	81.4	137.4	2.86
St. er. of mean	17	63	73	0.9	99	0.4	1.5	0.074	0.69	0.41	2.4	1.6	0.7	0.04	0.28	0.36	0.33	27.3	0.42	28.8	48.5	1.43

Table 3. Analyses of variances for yield, yield components, and protein in two crop seasons at Erzurum (1975-76, 1976-77).

Source of variation	d.f.	Grain yield	Straw yield	Total yield	Grain yield index	Number of fertile spike	Spikelets per spike	Kernels per spike	Grain yield per spike	1000 kernel weight	Test weight	Plant height
Year	1	57.47**	0.08	1.88	57.26**	18.35**	165.62**	6.29**	18.28**	169.52**	331.74**	24.30**
Error 1	6											
Varieties	29	15.55**	2.62**	3.19**	18.88**	2.64**	10.46**	9.98**	9.50**	45.13**	50.05**	21.31**
Year X Variety	29	6.06**	1.80*	2.43**	5.06**	2.20**	1.56	1.14	2.22*	11.92**	39.60**	2.94**
Error 2	174											
Total	239											

Source of variation	d.f.	Terminal inter-node length	Flag leaf length	Flag leaf width	Spike length	Number of til-lers per plant	Protein content of kernel	Crude protein yield of kernel	Crude protein yield of straw	Crude protein content of straw	Total crude protein yield	Zeleny sed. test value
Year	1	85.45**	15.04**	26.51**	9.90**	45.20**	0.77	48.62**	18.58**	57.91**	0.20	151.73**
Error 1	6											
Varieties	29	12.76**	5.87**	6.50**	14.34**	2.21**	8.82**	13.11**	2.21**	6.95**	5.25**	67.55**
Year X Variety	29	2.48**	3.57**	5.39**	1.21	2.72**	2.70**	5.65**	1.19	4.37**	4.13**	10.22**
Error 2	174											
Total	239											

Table 4. Correlation coefficients between measured characters.

		Grain yield 1	2	3	4	5	6	7	8	9	10
Straw yield	2	.184									
Total yield	3	.649**	.867**								
Grain yield index	4	.910**	.215	.295							
Number of fertile spike	5	-.106	.350*	.216	-.246						
Spikelets per spike	6	.286	-.106	.063	.331	-.496**					
Kernel per spike	7	.429*	-.157	.096	.517**	-.480**	.825**				
Grain yield per spike	8	.452*	-.167	.100	.531**	-.581**	.706**	.826**			
1000 kernel weight	9	.191	-.114	.009	.219	-.530**	.283	.167	.650**		
Hectoliter weight	10	.521**	.273	.475**	.412*	.316	-.127	.020	.113	.005	
Plant height	11	-.359*	.446*	.163	-.553**	.382*	-.340	-.388*	-.430*	-.298	.099
Terminal internode length	12	-.153	.375*	.213	-.312	.394*	-.376*	-.398*	-.449**	-.288	.215
Flag leaf length	13	.068	.033	-.016	-.055	-.048	.096	.281	.388*	.273	-.031
Flag leaf width	14	-.081	.407*	-.274	.255	-.322	.331	.446*	.422*	.103	-.248
Spike length	15	-.260	.099	-.055	-.296	-.111	.176	.111	.013	-.126	-.367*
Number of tillers per plant	16	.068	.179	.173	-.014	.695**	-.183	-.204	-.341	-.442*	.127
Crude protein content of kernel	17	.947**	.246	.671**	.839**	.000	.210	.355*	.334	.050	.623**
Crude protein yield of kernel	18	-.349*	.175	-.218	-.292	.483**	-.381*	-.376*	-.359*	-.431*	.184
Crude protein content of straw	19	-.217	.555**	.319	-.442*	-.005	.151	-.159	-.082	.117	-.195
Crude protein yield of straw	20	-.411*	-.052	.248	-.413*	-.133	.234	-.111	-.104	.036	-.405*
Total crude protein yield	21	.701**	.600**	.819**	.450**	.000	.278	.190	.238	.138	.421*
Zeleny sed. test value	22	.602**	.420*	.630**	.416*	.046	-.042	.126	-.035	-.257	.432*

Table 4. (concluded)

		11	12	13	14	15	16	17	18	19	20	21
Ternimal internode length	12	.826**										
Flag leaf length	13	-.057	-.157									
Flag leaf width	14	-.325	-.285	.202								
Spike length	15	-.136	-.182	.155	.071							
Number of tillers per plant	16	.143	.238	-.241	-.036	-.117						
Crude protein content of kernel	17	-.257	-.092	-.110	.030	-.285	.170					
Crude protein yield of kernel	18	.337	.167	-.145	-.188	-.106	.545**	-.066				
Crude protein content of straw	19	.215	.079	-.049	-.356*	.341	-.019	-.207	-.091			
Crude protein yield of straw	20	.039	-.097	-.077	-.093	.331	-.057	-.421*	-.302	.729**		
Total crude protein yield	21	-.092	-.037	-.152	-.227	-.036	.128	-.742**	-.046	.495**	.117	
Zeleney sed. test value	22	.062	-.030	-.082	-.213	.001	-.015	.663**	.071	-.009	-.236	.582**

Yayla-305, and F9M1B162. Significant positive correlations were found between the number of fertile spikes per square meter and plant height, ternimal internode length, number of the tillers per plant, and protein content of kernel. Number of fertile spikes was found to be significantly and negatively correlated with number of spikelets per spike, grain yield per spike, and 1000-kernel weight.

Number of spikelets per spike varied from 12.30 to 17.78 depending upon the variety. Odesskaya, Nugaines, B-2973 (Bolal), and Bezostaya produced the highest number of spikelets per spike. Correlation between the number of spikelets per spike and grain yield per spike was significant and positive; whereas, those between this character and terminal internode length, and crude protein content of kernel were significantly negative.

The number of kernels per spike ranged from 18.70 to 39.69, depending upon the variety. The foreign varieties and F9M2C177 (a Yayla-305 progeny) were at the top of the list in this respect. Significant positive correlations were found between the number of kernels per spike and grain yield per spike, flag leaf width, and the crude protein yield of kernel, while percent protein of kernel and plant height were significantly and negatively correlated with this character.

The varieties produced 0.62-1.54 grams of grain per spike on the average. Besides foreign varieties, F9M2C177 was one of the most productive lines in this respect. Significant positive correlations were found between grain yield per spike and 1000-kernel weight and flag leaf width.

One thousand kernel weight of the varieties ranged from 25.75 to 45.37 grams on the average. The varieties having the heaviest kernels were Bezostaya, Topbas, and Odesskaya. Significant negative correlations were found between 1000-kernel weight and number of the tillers per plant and crude protein content of the kernels.

Hectoliter weights of the cultivars varied from 70.62 to 81.97 kg on the average. The varieties, Bezostaya, B-2232, F9M1A112, and F9M1B162 had the highest hectoliter weights. Significant positive correlations were found between hectoliter weight and total crude protein yield, crude protein yield of the kernel, and Zeleny sedimentation test value.

Plant height of varieties ranged from 66.9 to 123.7 cm on the average. B-3667, Village-8, and B-3079 were found to be tallest; whereas, B-2973 and Nugaines were the shortest varieties. A significant positive correlation was found between plant height and terminal internode length.

B-434, Village-8, and Topbas had the longest terminal internode lengths among the varieties.

Flag leaf lengths ranged from 15.1 to 21.9 cm depending upon the variety. The longest flag leaves belonged to B-2551, B-2973, and B-434. This character gave a significant and positive correlation only with grain yield per spike.

Flag leaf widths of all varieties varied within a range of 0.96 to 1.47 cm. B-2973, Village-8, and F9M2C177 had the widest flag leaves. A significant negative correlation was found between the flag leaf width and crude protein content of straw.

Average spike length of varieties varied within a range of 6.53-10.56 cm. Village-6, Odesskaya 51, Topbas, and Yayla-305 had the longest spikes among the varieties studied. Spike length was correlated significantly and negatively only with the hectoliter weight of kernel.

The number of tillers per plant varied from 2.17 to 4.58. The native varieties, and especially Yayla-305, F9M1B162 and Village-8, were found to have the highest number of tillers per plant. The only significant positive correlation was found between number of tillers per plant and crude protein content of kernel.

Highest protein contents were produced by Village-2, B-3079, and Village-8. The varieties ranged from 13.56-17.16%.

The crude protein yield of varieties varied from 302.6 to 669.9 kg per hectare. F9M1B162, Bezostaya, B-2232, and F9M2C177 took the first places among the varieties. Significant positive correlations were found between crude protein yield and grain yield index, hectoliter weight, grain yield, total yield, total crude protein yield, and Zeleny sedimentation test value. On the other hand, crude protein content of straw was found to be significantly and negatively correlated with crude protein yield.

It was determined that the crude protein content of straw varied from 3.03 to 6.17%. B-2965, Odesskaya-51, and Yumusak were the highest in this trait.

Crude protein yield of straw varied from 286.0 to 661.8 kg per hectare depending upon the variety. B-2965, Odesskaya-51, and Village-8 were the most productive varieties in this respect. Crude protein yield of straw was significantly and positively correlated with crude protein content of the straw and total crude protein yield.

Total crude protein yields of the varieties varied from 680.0 to 1044.0 kg per hectare. Nugaines, Village-8, and F9M1B162 produced the highest amounts of total crude protein per hectare. A significant positive correlation was found between total crude protein yield and Zeleny sedimentation test value.

Zeleny sedimentation test values varied from 11.60 to 54.00 ml depending upon the variety. B-3079, F9M1B162, and Bezostaya had the highest sedimentation values.

Conclusions

As a result of the studies made on the varieties involved in this experiment and the correlations that have been observed between total yield and grain yield, grain yield index, number of kernels per spike, weight of kernels per spike, hectoliter weight, crude protein yield of the kernel, total crude protein yield and Zeleny sedimentation test values, we believe that this characteristic should be taken into consideration in the selection of the parents in wheat breeding.

It has been determined that some of the varieties in this study have important potential with regard to yield and morphological characteristics. The native common winter wheat varieties show superiority with regard to crude protein content of kernels and straw yield. These varieties constitute an important genetic source in the wheat breeding program that will be planned for the region.

Varieties in the experiment yielded crude protein and sedimentation values higher than the standards set for high quality wheats. This indicates that Eastern Anatolia region has an important potential for production of high quality wheats.

The F9M1B162 line which has superior characters with regard to kernel yield, straw yield, total crude protein, Zeleny sedimentation and resistance to yellow rust, smut, bunt, and lodging is a potentially valuable variety for the Eastern Anatolia region of Turkey.

References

Engledow, F. and S. M. Wadham. 1923. Investigation of yield in the cereals. Part I. J. Agric. Sci. 13:390-439.

Genc, I. 1972. Yerli ve yabanci ekmeklik ve makarnalik bugday cesitlerinde verim ve verime etkili baslica karakterler uzerinde arastirmalar. A. U. Zir. Fak. Bit. Yet. ve Isl. Kursusu.

Grafius, J. E. 1956. Components of yield in oats. A geometrical interpretation. Agron. J. 48:419-423.

Grafius, J. E. 1964. A geometri of plant breeding. Crop Sci. 4: 241-246.

Hsu, P. and P. D. Walton. 1970. The inheritance of morphological and agronomic characters in spring wheat. Euphytica 19:54-60.

Hsu, P. and P. D. Walton. 1970. The quantitative inheritance in spring wheat of morph. structure above the flag leaf node. Can. J. Genet. Cytol. 12:738-742.

Hsu, P. and P. D. Walton. 1971. Relationships between yield and its components and structure above the flag leaf node in spring wheat. Crop Sci. 11:190-193.

Jain, R. P., M. Y. Khan, and B. V. Sing. 1969. A study of association in various quantitative characters in wheat. Madras Agric. J. 56:134-136.

Lupton, F. G. H. 1969. Physiological parameters of yield in wheat. Genetica Agraria 23:457-464.

Schmidt, J. W. 1975. Development of winter varieties for low rainfall, non-irrigated areas. International Winter Wheat Conference Proceedings. Zagreb, Yugoslavia.

Simpson, G. M. 1968. Association between grain yield per plant and photosynthetic area above the flag leaf node in wheat. Can. J. Plant Sci. 48:240-250.

Sing, B. V. and R. Pratap. 1967. Correlation studies in Indian wheat. Madras Agric. J. 54:487-488.

Smocek, J. 1969. A contribution to the analysis of associations between economic yield components and four morpho-physiological subcharacters in wheat. Biologia Pl. 11:260-269.

Thorne, G. N. 1966. Physiological aspects of grain yield in cereals. In The Growth of Cereals and Grasses. Butterworths, London. pp. 88-105.

Voldeng, P. D. and G. M. Simpson. 1967. The relationships between photosynthetic area and grain yield per plant in wheat. Can. J. Plant Sci. 47:359-365.

Watson, D. J. 1962. The physiological basis of variation in yield. Advances in Agron. 4:101-144.

WHEAT AGRONOMY IN BANGLADESH RESEARCH RESULTS AND FARMER PRACTICES

J. Bolton, A. H. Talukdar and C. G. Swenson
Bangladesh

Abstract

Wheat in Bangladesh is grown as a winter (rabi) crop from mid-November to March, following rice or jute in the monsoon. Average rainfall during these five months is 195 mm, but extremely variable from year to year. In most years a lack of moisture limits yields. Experiments show that irrigation at the crown-root initiation stage is more effective than at other growth stages. For maximum yields total evapotranspiration was measured at 300 mm, only slightly less than the open-pan evaporation.

Surveys of farmer irrigation practices show that they recognize the importance of early irrigation if ample water is available but tend to irrigate late if only one irrigation can be given.

Most farmers also plant at the optimum time and use the correct seed rate (100-120 kg ha^{-1}) as shown by research results but nitrogen rates were on average less than optimum with a wide range of usage. Phosphate and potassium used were on average less than recommended but modal rates were nearer to the recommended rates than for nitrogen. Recommended fertilizer rates are 100 kg N, 60 kg P_2O_5 and 40 kg K_2O per hectare.

Future agronomic research will concentrate on primary tillage methods and the conservation of residual soil moisture, methods of planting to achieve optimum stands and studies of mixed cropping of wheat with other crops, especially pulses. Mixed cropping is widely practiced in some areas.

Introduction

Wheat production in Bangladesh has increased rapidly in recent years from both increased areas and yields. Another conference paper (Razzaque and Hossain, 1980) will describe these events and the research and development procedures followed. This paper concentrates on the results of agronomic research and how far the optimum procedures found are followed by the small farmers, as shown by surveys in several wheat-growing Districts.

Bangladesh is not strictly a semi-arid country since, over the whole year, average rainfall exceeds evapotranspiration. However,

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the rain is strongly seasonal with heavy rain for 6 months in the summer when rice or jute is grown on almost all the land and little rain in the remaining 6 months which includes the wheat season from mid-November to March. Average rainfall and open water evaporation during the year are shown in Figure 1. Irrigation, which is only available to about half the wheat farmers is from small reservoirs (tanks), rivers, shallow wells or deep tubewells.

Almost all wheat is grown by small farmers with an average of 0.35 ha each in 4 separate fields (in some areas up to 10). The land-tenure system is very complex and will not be described in detail here. However, whether or not the grower is an owner, lessee or sharecropper has a considerable influence on the agronomic methods used, cash inputs used, and financial returns to the enterprise.

Primary Tillage

After the rice or jute harvest, the land is ploughed 4-8 times with a wooden "country" plough using a pair of bullocks to a depth of only about 10 cm. The puddled horizon created for paddy is often untouched and in some soil types is a barrier to penetration by wheat roots. This causes the crop to be far more susceptible to moisture stress than it would otherwise be. After ploughing, the seedbed is prepared by "laddering" -- a form of harrowing 3-4 times. If water is available some farmers (30 percent in the survey) pre-irrigate about 10 days before the expected date of seeding to ensure germination.

Planting

Almost all seed is broadcast because drills are unavailable and the labour cost of line-sowing by hand is high. Some unpublished experiments showed 10-15 percent higher yields from line-sowing and, for broadcast seed, yield increases up to a seed rate of 120-140 kg per hectare. In the survey 70 percent of farmers used seed rates in this range or higher; possibly they are trying to compensate for seed or seedling losses from inefficient broadcasting. Poor stands are very commonly seen and could be responsible for much loss of yield. More research is needed on seed rate and planting method interactions under farmers' conditions.

Planting date experiments (Razzaque, 1977) over several years have shown maximum yields from mid-November sowing when soil temperatures have fallen to about 20°C. Early planting causes poor stands from seedling blight, poor tillering and sometimes water logging from late monsoon showers. Germinating wheat is very sensitive to water logging. With late planting, low soil moisture is the major problem. Sixty percent of the farmers planted at the correct time in November but the planting season extended through December to mid-January because of late harvest of the "Aman" season rice crops.

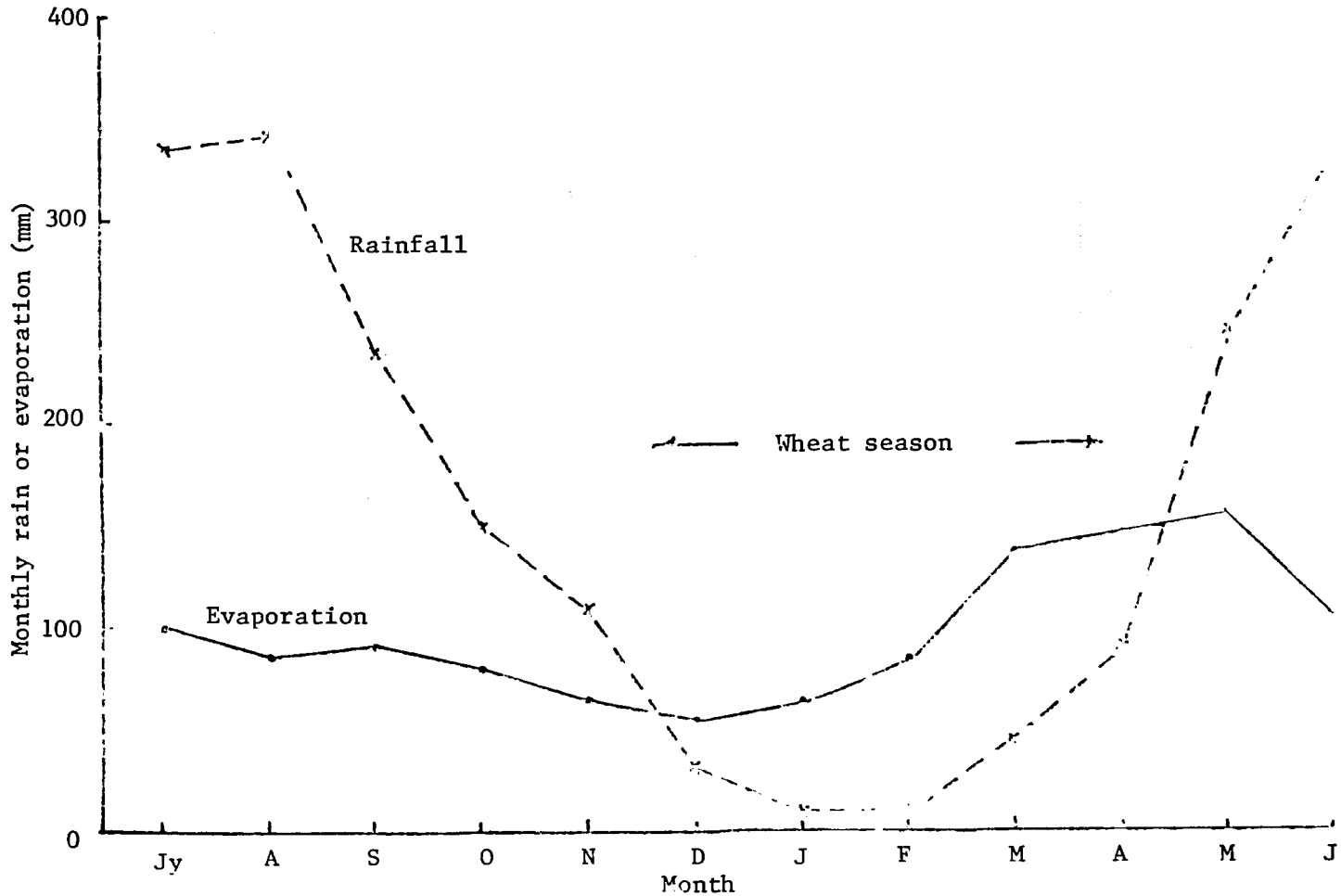

Figure 1. Monthly rain and open-pan evaporation (mm) for the Dacca district of Bangladesh. 25-year averages.

Moisture Relationships

Two series of experiments have shown that irrigation at the crown-root initiation stage (21 days after germination) was the most effective in increasing yields. Smaller responses were obtained from water applied at the maximum tillering, boot and grain-filling stages -- in that order. Some results of these trials are shown in Table 1. Other workers in the sub-continent have obtained similar results (Eckert et al. 1978; Singh et al. 1979). However, Salter and Goode (1967) concluded from a study of the literature that wheat is especially sensitive to moisture stress at the boot and grain-filling stages. These different conclusions may be because most research has been done in temperate conditions with well-cultivated soils rather than on shallowly-cultivated soils in the tropics.

Table 1. Effects of irrigation at different growth stages on the yields of wheat.

Experiment year	No irrigation	Irrigation at days after planting (approx.) 21	21 + 42	21 + 42 + 56	21 + 42 + 56 + 80	S.E.
Series 1			t/ha grain			
1. 1976-71	1.33	3.01	3.40	3.40	3.78	± 0.45
2. 1977-78	2.85	4.27	4.34	3.94	4.37	± 0.35
Series 2						
1. 1978-79	1.52	2.85	3.32	3.55	--	± 0.42
2. 1978-79	1.55	2.08	2.31	2.50	--	± 0.46

21 days = Crown root initiation.
42 " = Maximum tillering.
56 " = Booting.
80 " = Grain filling.

In one experiment (series 2) moisture use from rain, the soil and irrigation were accurately monitored. Total losses ranged from 116 mm in the unirrigated plots to 270 mm with 3 irrigations. Class A pan evaporation over the growing period was 310 mm. Apparent efficiencies of water use ranged from 140 down to 70 kg grain/ha/cm of water used without added nitrogen fertilizer but with increasing rates of irrigation. With 200 kg N/ha water use efficiency ranged from 140 to 160 kg grain/ha/cm with increasing rates of irrigation -- showing that efficient water use must be matched by the correct nitrogen rate.

Other authors have given water use efficiency data for wheat. Doorenbos et al. (1978) give rather a low figure of 80-100 kg/ha/cm and Singh et al. (1979) give a mean of 130 from their experiments. Rahman et al. (1979), in Bangladesh, found water use efficiencies

of between 84 and 151 in their experiment with different rates of irrigation and 100 kg/ha of N, with the maximum from irrigation at tillering and booting stages.

All these results seem to show that wheat in Bangladesh needs 300 mm of water in 120 days for a full crop, of which 100 to 150 mm can be supplied from the soil (if at field capacity on planting) depending on soil type. The remaining water requirement of 100 to 150 mm must be from rain and irrigation. It is interesting that in a temperate climate (UK) total evaporation from spring wheat with a 150-day growing period was almost the same at 320 mm (French, Long and Penman, 1972).

Of the 80 plots surveyed in the 1978-79 season, 54 were irrigated and about half of these were given water before sowing in this unusually dry season. On average, the first post-germination irrigation was given at 24 days except for those farmers who only irrigated once when the average was at 48 days. On average the second post-planting irrigation, if given, was at 52 days and the third at 70 days. No plots were irrigated later than 80 days after planting. These results show that farmers' irrigation practices roughly agree with the research findings but the importance of early irrigation needs to be stressed, especially if limited water is available. Average yields were significantly larger in the irrigated (2.45 t/ha) than the unirrigated (2.04 t/ha) plots but the difference was surprisingly small, showing that yields were limited by some other factors as well as water, most probably low stands and too little nitrogen fertilizer.

Nutrition

Many simple fertilizer experiments have been made from which the current recommendations of 112 kg N, 90 kg P_2O_5 and 67 kg K_2O per hectare for irrigated and 90 kg N, 67 kg P_2O_5 and 45 kg K_2O for non-irrigated wheat were derived (Bangladesh Agricultural Research Council, 1979). However, for P and K, little research has been done to relate responses to soil analyses or soil type and it is known that there are large variations. Such research is now being organized. For nitrogen, some response curves at different levels of irrigation have been determined in the unusually dry 1978-79 season. Figure 2 gives the results of one experiment showing very small and uneconomic responses to nitrogen without irrigation, and optimum rates of 100 to 120 kg/ha with one, two or three irrigations.

In the 1978-79 survey, almost all the wheat farmers applied nitrogen, 75% used phosphate and 65% potassium. Average rates used were 67 kg N, 42 kg P_2O_5, and 22 kg K_2O per hectare but these figures hide wide variations, probably depending on both availability of supplies and cash or credit for purchase. It seems, therefore, that there is much scope for increased production from increased fertilizer use, especially of nitrogen.

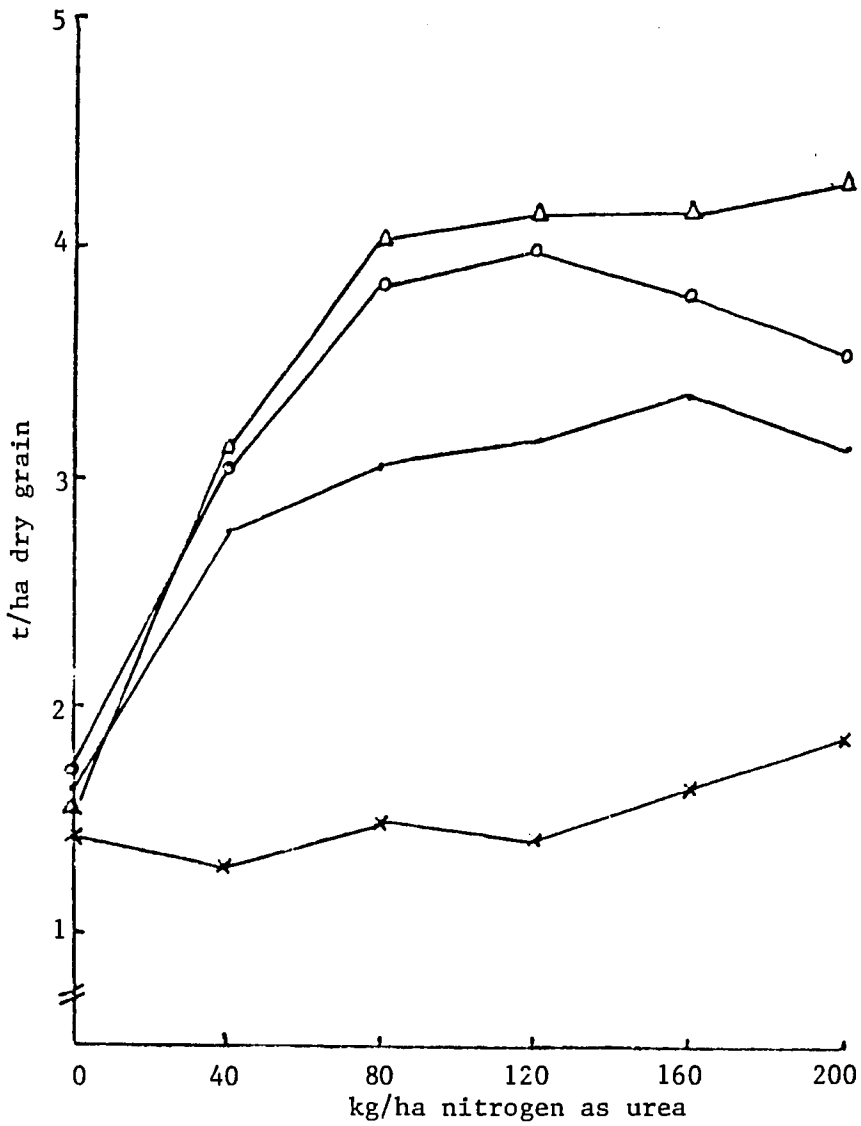

Figure 2. Nitrogen response curves for wheat in Bangladesh 1978-79 (Joydebpur) with none (x), one irrigation at 21 days (•), two irrigations at 21 and 42 days (°) and three irrigations at 21, 42 and 56 days (Δ).

Other nutrition problems which are suspected to occur in some areas are sulphur, zinc, and possibly manganese and copper deficiencies. Little research has yet been done on these problems.

Pests and Diseases

Bangladesh wheat crops are comparatively free from fungal pathogens and insect pests. The principal pathogens are leaf rust, against which resistant varieties are the main defense, loose smut, helminthosporium and alternaria, and seedling blight. Seed dressings against some of these diseases are not used either by farmers or the seed agencies. Of the insect pests, wireworms and cutworms occasionally cause damage. The surveys showed that about 10 percent of farmers used insecticides but none used fungicides. This is probably based on their experiences with rice pests rather than a rational use based on observed insect damage.

Probably the largest pest losses in the fields are from rats and surveys in the 1978-79 season gave estimated yield losses of about 12 percent (Bangladesh Agricultural Research Institute, 1979). There is also bird damage at the seed and seedling stages.

Economic and Social Factors

Bangladesh peasant farmers are among the poorest in the world, but surveys have shown surprisingly few (less than 10 percent) used institutional credit sources or loans from family or moneylenders. However, there was probably hidden credit in the form of barter arrangements for both physical inputs and bullock power and labour. Many economists now recognize that the poorest farmers are more concerned with cash flows than with full cost/benefit ratios and will limit as much as possible cash payments, and, of course, risks. Returns from wheat cultivation depend to a large extent on land tenure arrangements. Owner-cultivators generally make reasonable profits on both full-cost and cash-cost accounting but share-croppers, who must give half the crop to the landlord, make losses on full-cost and only marginal profits on cash-cost accounting.

Some relevant statistics from the surveys in 1978-79 are given in Table 2.

Table 2. Some relevant statistics for wheat production in Bangladesh, 1978-79.

Average national yield	1.9 t/ha
Average field size	0.12 ha
Average area of wheat/farmer	0.36 ha
Labor requirement including threshing and drying	212 man days/ha
Wage rate for hired labor	US$0.55/day
Average proportion of crop sold	40%
Farmers using own seed	52%
Estimated wheat areas, 1979-80	500,000 ha
Government support price, 1979-80	US$202/t

Sources: Bangladesh Agricultural Research Institute (unpublished); Ministry of Agriculture and Forests, Economic Research Section (1979).

Conclusions

It is now fairly clear that wheat areas in Bangladesh will continue to expand for many more years, both on land which now remains fallow in the winter season and by displacing more traditional crops such as pulses and rice (where limited irrigation is available). Further agronomic research is especially needed in the fields of cropping systems, primarily to ensure optimum planting dates; moisture conservation including tillage practices; refining of the fertilizer recommendations, for phosphorus and potassium; sulphur and micronutrient studies and pest and disease control.

References

Bangladesh Agricultural Research Council. 1979. Fertilizer guide for major crops of Bangladesh. BARC Soils and Irrigation Publication No. 4, Dacca.

Bangladesh Agricultural Research Institute Vertebrate Pest Division. 1979. Rat damage study in wheat. Monthly Report No. 4, April 1979. Mimeographed.

Doorenbos, J., A. H. Kassam, C. Bentvelsen, and G. Uittenbogaard. 1978. Yield responses to water. U. N. Econ. Comm. for West Asia Reprint. (Summary of FAO Irrigation and Drainage paper.)

Eckert, J. B., N. M. Chaudhry and S. A. Qureshi. 1978. Water and nutrient response of semi-dwarf wheat under improved management in Pakistan: agronomic and economic implications. Agron. J. 70:77-80.

French, B. K., I. F. Long, and H. C. Penman. 1973. Water use by farm crops. II. Spring wheat, barley, potatoes (1969); potatoes, beans, kale (1968). Rep. Rothamsted Experiment Station for 1972, Part 2:43-61.

Ministry of Agriculture and Forests, Bangladesh, Agroeconomic Research. 1979. 1978-79 wheat cultivation practices, costs and returns. Costs and Return Surveys, 1978-79. Vol. VI.

Rahman, S. M., S. U. Talukdar, A. K. Kaul and M. R. Biswas. 1979. Yield response of a semi-dwarf wheat variety to irrigation on a calcareous brown flood-plain soil of Bangladesh. Mimeographed. Inst. Nuclear Agric. and Bangladesh Agric. Univ., Mymensingh.

Razzaque, A. 1977. Review of ten years on modern wheat research in Bangladesh. Proc. Workshop March 1977. Publication 27, Bangladesh Rice Research Institute, Joydebpur.

Razzaque, A. and A. B. S. Hossain. 1980. Wheat production in Bangladesh -- an effective research and production approach. Proceedings this Conference.

Salter, P. J. and J. E. Goode. 1967. Crop responses to water at different stages of growth. Res. Rev. No. 2. Commonwealth Bureau of Horticulture and Plantation Crops pp. 17-29.

Singh, N. T., A. C. Vig, R. Singh and M. R. Chaudhury. 1979. Influence of different levels of irrigation and nitrogen on yield and nutrient uptake by wheat. Agron. J. 71:401-404.

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THE PERFORMANCE OF DWARF AND SEMIDWARF WHEATS IN NORWAY

K. Ringlund
Norway

Abstract

Since 1967 we have been incorporating Mexican dwarf and semidwarf wheats into our breeding programs. The early Mexican varieties were themselves poorly adapted to our climatic conditions. The main problems were lack of resistance to septoria and some other leaf diseases. They also had relatively high base temperature requirements for maturation. Data from yield trials on the performance of lines from crosses between Mexican and Scandiravian wheat varieties will be presented.

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Introduction

The wheat growing area of Norway is situated between 58 and 62 degrees north. The climate is marginal for wheat growing. Some of the problems encountered in high latitude areas are similar to those encountered in high altitude regions in the tropics and subtropics. Our results, therefore, might have some general interest.

Differences between landvarieties and modern varieties.

Comparisons between land varieties of wheat grown in Scandinavia at the beginning of this century, and varieties grown commercially today, show that the modern varieties have shorter and stiffer straw, better lodging resistance, higher harvest index, and higher grain yield. This was demonstrated in an experiment with 8 spring wheat varieties grown at the Agricultural University of Norway in 1979 (Table 1). The results from this experiment show an yield increase of 57 kg/hectare for each cm decrease in plant height. Lodging resistance was also highly correlated to plant height.

Performance of 4 Mexican spring wheat varieties.

In the late nineteen sixties dwarf genes were introduced into our breeding program. Most of the dwarf parents came from the CIMMYT nurseries.

Agricultural University, 1432 AS-NLH

Table 1. Results from a yield trial with 8 spring wheat varieties in 1979.

Variety	Year of Release	Yield KG/HA	High CM	Lodging %
Børsum	Land variety	3770	99	77
Diamant II	1938	4080	97	57
Fram II	1940	4080	97	98
Norrøna	1952	4180	95	97
Rollo	1963	4490	91	23
Møystad	1966	4170	97	50
Runar	1972	4460	89	17
Reno	1974	4580	87	5

In 1970 we included 4 Mexican varieties in 4 yield trials. A summary of these trials is presented in table 2. None of the Mexican varieties gave acceptable yields. Test weights were low, and falling numbers were very low. Three of the varieties seemed early, but both the early maturity and the low yield were due to heavy attacks of septoria nodorum and possibly helminthosporium sativum.

Table 2. Results from 4 yield trials with 4 Mexican and 3 Norwegian spring wheat varieties in 1970.

Variety	Yield KG/HA	Days to Maturity	Lodging %	KG/HL	Falling Number
Sonora 64	1990	102	3	75.0	136
Tobari 66	1910	102	7	76.9	170
Inia 66	1470	102	3	74.3	105
Super X	2320	106	2	74.1	104
Rollo	3100	104	8	77.4	272
Møystad	3300	105	23	76.8	250
Runar	3340	102	3	79.2	336

In spite of these discouraging results, it was recognized that all these and other semidwarfs had desirable characteristics such as short straw, good tillering capacity and high number of kernels per spike. Many of the new introductions were heading earlier than the Scandinavian material, but without leaf diseases they were maturing later.

Adaptation of the dwarf and semidwarf varieties to a high latitude, semi maritime climate seemed to require a change in at least two factors, namely resistance to leaf diseases and ability to mature at low temperature.

Performance of semidwarf breeding lines

Progeny from single and double crosses, and from recurrent selections all involving dwarf, semidwarf and traditional Scandinavian varieties as parents, were tested in yield trials in 1976-79. Results are summarized in table 3.

Table 3. Summary of 4 years of yield trials with semidwarf spring wheats.

Variety or Line	Yield KG/HECTARE	Height in CM	Lodging %	Days to Maturity	1000 Kernel Weight	KG/HL	Falling Number	Dormancy Index	Mildew	Septoria
Runar	4150	84	11	117	39.9	80.3	133	11	18	7
Reno	4350	84	12	118	36.7	80.1	186	20	16	15
T 68038-2	4520	70	23	119	33.8	79.1	170	37	5	5
T 3014	4450	73	12	115	36.4	78.7	163	16	4	1[illegible]
T 638-198	4490	74	9	118	37.3	79.3	128	30	11	20
T 7380	3860	63	0	123	29.7	76.5	212	29	6	20
T 7388	4060	63	0	121	40.3	79.1	161	21	4	19
T 8020	4320	73	13	116	34.3	79.4	119	9	6	20

Table 4. Plant Height and yield of 5 spring wheat varieties and yield response to high doses of Nitrogen.

Variety	Height in CM	Yield in KG/HA at 120 KG N	Yield response to nitrogen each level compared to 120 KG N		
			160 KG N	200 KG N	240 KG N
Runar	78	4810	+ 110	+ 340	+ 370
T 3014	69	5030	+ 100	+ 110	- 90
T 7201	59	4060	- 30	+ 100	+ 270
T 7380	59	4850	+ 60	+ 120	+ 160
T 7322	41	3410	+ 30	- 120	+ 100
Mean		4430	+ 60	+ 110	+ 160

The semidwarf lines have higher septoria attacks but less mildew than the standard varieties 'RUNAR' and 'RENO'. The lines with approximately 10 cm shorter straw than the standards, all have high yields and satisfactory quality data. The two lines with a 20 cm reduction in plant height compared to the standards, do not have satisfactory yields. The semidwarfs with high yields do not have improved lodging resistance in spite of a reduction in plant height.

Response to nitrogen

Fundingsrud (1979) conducted two experiments with nitrogen levels from 120 to 240 kg N per hectare with the standard variety 'Runar' and four breeding lines with different plant height. Results from his experiments are shown in table 4.

'RUNAR' responded better to high nitrogen levels than the four breeding lines. T3014 and 'RUNAR' had some lodging at 200 kg N and 240 kg N, whereas the shorter lines did not lodge.

The protein content of grain and straw increased with increased nitrogen levels, and there was a significant difference between varieties in protein content of the straw. 'RUNAR' and T3014 had 2.7 and 2.8 per cent protein in the straw, respectively, and the other three lines had from 3.5 to 5.5 per cent. No correlation was found between protein content in the grain and the protein content in the straw over varieties.

Conclusions

The varietal improvement in potential grain yield of wheat is mainly due to increased harvest index. Up to now this has been achieved by reducing plant height. The semidwarf varieties developed at CIMMYT are important sources for a continued increase in the harvest index.

In marginal wheat growing areas such as in Norway, adaptation to the local climate and the local disease spectrum is very important. Introductions of the new geotypes, therefore, are only possible through a breeding program.

Literature Cited

S. Fundingsrud 1979. Store nitrogenmengder til fem vårhvetesorter. Hovedoppgave ved Norges landbrukshøgskole. 56 sider.

WHEAT PRODUCTION AT THE STATE FARM (PPK) KUTJEVO IN THE PERIOD 1975-1979

M. Cvetko
Yugoslavia

Natural conditions for wheat production at PPK Kutjevo.

PPK Kutjevo is situated in the region of Slavonija in Croatia. The plain of 24 km^2 is surrounded by mountains and the area is named "Pozeska kotlina" after the town of Slavonska Pozega. Owing to the wine-growing hills and other natural resources, it has been called "Valis aurea" (Zlatna Dolina) from ancient times.

On the basis of analysis of climatic factors in several consecutive years, we can conclude that wheat production is possible in this climate and production results confirm this.

The following table shows the average temperature and precipitation value in the 10 year period of 1960-1970.

Average monthly temp. / °C / Total of precipit. / mm		Month 1	2	3	4	5	6
°C	10.7	-0.1	0.6	5.6	11.3	15.2	19.2
mm	800	66	71	81	42	58	39

Average monthly temp. / °C / Total of precipit. / mm		Month 7	8	9	10	11	12
°C	10.7	21.1	20.4	16.4	11.5	5.7	2.3
mm	800	55	88	111	75	71	43

Temperature.--The average monthly temperatures of 11.5°C in October and 5.7°C in November render wheat germination, emergence and tillering possible. March with 5.6°C and April with 11.3°C are very similar to November and October, which means that wheat has good conditions for intensive tillering, as well as for normal growth and development. May is a variable month. In the period of 10 years average monthly temperatures varied between 13.1 and 16.0°C, minimal ones between 1.5 and 2.3°C, and maximal ones between 22 and 30.5°C.

Precipitation.--In the period of 10 years the total precipitation varied between 642.7 and 986.4 mm, which meets the requirements of wheat. However, there are extremes in the pattern of precipitations. In May, when wheat is in the most delicate development stage, it varies between 4.9 mm and 150.7 mm.

PPK, Kutjevo

Soil.--Pseudoclay soil type of heavy physical structure and poor air-water regime dominate here. The content of organic matter is low, between 1.5% and 2% and the pH value is between 4.1% and 5.3%. The quantity of active phosphorus varies between 10 and 16 mg P_2O_5/100 g of soil which is low, and there is a wide span of potassium - between 9.2 and 36 mg/100 g of soil.

The equipment.--The seeded area consists of the following crops: 45-50% wheat, 30-35% maize, and 8-12% oil-crops. The remaining percentage is devoted to industrial crops, forage crops and vegetables.

Operating machines, primary processing and surface processing machines, as well as manuring and transportation machines are used for all culture according to circumstances. Other machines are specialized according to the requirements of a group or individual crops. Grain combines are used for harvesting wheat, commercial maize and oil-crops. As wheat occupies almost 50% of the seeded area, the capacity of combines is used mainly for this crop.

Wheat production process

Selection of varieties.--The farm is oriented exclusively to the growing of domestic varieties of wheat due to their extraordinary agronomic value. The table below shows the assortment in the period between 1975 and 1979.

	% of areas sown with wheat				
Variety	1975	1976	1977	1978	1979
Zlatna dolina	86.41	82.26	77.81	72.38	35.81
Sanja	8.71	6.00	11.13	13.00	2.78
Partizanka	4.80	11.74	11.06	8.11	-
NS Rana 2	-	-	-	2.94	17.55
Super-Zlatna	-	-	-	1.70	19.40
Zlatoklasa	-	-	-	1.70	29.94
Other varieties	-	-	-	0.17	1.51

The variety "Zlatna dolina" prevailed in the period between 1975 and 1979 due to its extraordinary agronomic characteristics However, the other varieties confirmed their value and entered into the assortment, as the table shows, but the variety "Zlatna dolina" has kept the leading place.

Seventy-five to 80% of the total area under wheat is seed production from the highest to the lowest seed categories. The seed is used by the producers in the country and partly is exported to European countries.

The farm complex organizes a wheat field day each year and a wheat symposium on the Yugoslav level is also held. In macro-experiments, 30-45 domestic varieties and 5-8 varieties of wheat from other countries are sown. The results obtained for each variety sown in the macro-experiments are recorded over years and the data are used for selection of varieties for extensive production.

Preceding crop.--Repeated sowing on the same field is not practiced as there is a possibility in this climate of attack of root and foot rots (Ophiobolus and others). Therefore, all the other crops, mainly maize, are preceding crops for wheat. Due to the climatic conditions early hybrids of maize, group 400, are grown and so the area is free sooner for wheat sowing.

Primary tillage.--As the physical and chemical properties of the soil are unfavorable, the soil is plowed for wheat to the depth of 30-35 cm.

Secondary tillage.--Preceding crop and soil moisture determine the preparation of the soil for sowing. After plowing, discing and macro-leveling follow; then the tillage is finished with a machine for seed bed preparation and micro-leveling

Fertilizing.--In the system of fertilizing we have taken into account the requirements of wheat, soil fertility, agro-technical characteristics of the climate, level of agro-techique, the preceding crop, and variety. On the basis of these, quantity, proportion, manner and time of fertilizing are determined.

The amount of NPK nutrients ranges from 1:0.6-0.8:0.4-0.6, and the quantity of N ranges from 140-160 kg/ha.

Thirty to 50 kg of N is applied before soil preparation preceding the sowing, and the whole quantity of P_2O_5 and K_2O is applied upon plowing and is disced down. In the spring, the remaining N fertilizer is applied in 2 to 3 top-dressings.

The first top-dressing with 40-55 kg of N is given at the time when active growth of the wheat is started. The second top-dressing is given at the time of intensive tillering with a quantity between 40-70 kg/ha N which is determined by the requirement of the crop and on the basis of plant analysis. The third top-dressing is applied, as necessary, in the late stem-extension period before heading, with 30 kg N/ha, also on the basis of plant analysis.

Sowing.--The optimal period for sowing is between the 10th and 25th October. The tolerant period is from the 5th to 9th October to the 26th October - 10th November. Rate of sowing is determined by crop density at harvest (number of ears per m^2). Tillering capacity, weight of 1000 kernels,percent of germination, and seed purity are factors which determine number of seeds sown per m^2. Depending on the characteristics and category of the variety, 450-600 viable seeds are sown on a square meter.

Weed and insect control.--The wheat is mainly protected against weeds and Lemma spp. Spraying against weeds is done with a combination of herbicides as follows: MCPP (Deherban fluid or Dicofluid) in the quantity of 4 l/ha for broad-leafed weeds and Dicuran 500 FW in the quantity of 3 l/ha for grass weeds. Spraying against Lemma is done by Lebaycid in the quantity of 1.5/ha or by some other acceptable chemical.

Harvest.--The wheat is harvested at full ripeness in a single operation. The capacities of the combines and of the accompanying machinery equipment permit all the harvesting work to be finished in 12 working days.

Special measures in seed wheat production.--a). A span of 24 cm is left unsown in each 2 meters of sown area in order to have better control of each area at the time of biological weeding. b) The wheat is sown at the optimal period. c) In order to produce seed of the best quality the following number of seeds are sown on a square meter: Super elita 450, Elita 550, and other classes 550. d) A special treatment of fertilizing is used, especially increasing the number of top-dressings. e) All categories of seed fields are biologically weeded. f) The wheat seed is combined with a maximum of 14% moisture and special attention is paid to the reduction of grain-breaking and to keeping the reproduction sorts pure. g) The transport equipment is well cleaned when some other variety is to be transported.

The analysis of climatic factors and their influence on yield in the period from 1975 - 1979.

Weather conditions in the analyzed years are shown in Table 1. Only a few extremes will be pointed out in this period.

Heavy precipitation, 150.7 mm in May 1975 fell at the time of flowering and had negative influence on the fertilization. A storm accompanied by rain of 46.6 mm in June 1976 lodged the wheat at its roots. Climatic conditions of 1976/77 were extraordinarily favorable for the growth and development of wheat. May, 1978, with an average temperature of 13.4°C and minimal temperature of -1.5°C was the coldest month in the last 10 years. All of May and half of June 1979 were extremely dry with the total precipitation amounting to only 20.4 mm.

Grain yields of wheat at PPK "Kutjevo" and at state farms of Slavonia (Osijek region) in the period from 1975 to 1979.

Area	Year					Av. X	Stand deviation	Coef. variation V%	Trend q/ha
	1975	1976	1977	1978	1979				
PPK Kutjevo	45.4	57.4	50.3	52.0	55.0	52.02	4.11	7.91	+1.38
Slavonia (Osijek region)	41.2	59.2	52.9	47.5	49.6	50.08	5.95	11.87	+0.51

The average yield at PPK "Kutjevo" in the five-year period from 1975-1979 amounted to 52.02 q/ha with standard deviation of 4.11 q/ha and coefficient of variation 7.91%. The trend of yield increase amounted to 1.38 q/ha in this period.

The average yield of PPK "Kutjevo" surpassed the average yield of Osijek region by 1.94 q/ha. Variability of yields in the Osijek

Table 1. Temperature and precipitation values in the vegetative period from 1975-1979 at State Farm Kutjevo.

Year	Climatic condition	MONTH 8	9	10	11	12	1	2	3	4	5	6	7	
	Average °C	21.1	16.2	7.0	5.4	3.3	2.5	1.6	7.8	10.3	16.0	17.8	19.9	
1974	Min.	10.3	3.6	0.4	- 2.5	- 3.5	- 6.0	- 6.5	- 4.2	6.8	4.5	6.5	8.5	
1975	Max.	28.8	29.0	17.0	19.5	15.0	14.4	13.0	19.0	24.5	27.0	29.5	30.5	
	Precipitation/mm	163.8	84.7	163.2	45.0	44.5	27.0	6.9	38.0	65.9	150.7	70.8	77.3	942.5
	Average °C	19.3	18.1	10.1	4.3	1.1	0.7	- 0.3	2.1	10.8	14.7	16.9	20.2	
1975	Min.	10.3	6.5	0.0	-11.5	- 7.5	-15.0	-15.0	-10.5	0.0	- 0.5	6.5	7.5	
1976	Max.	28.8	27.5	27.0	17.0	13.5	12.5	15.0	18.0	24.0	25.5	29.0	32.2	
	Precipitation/mm	75.6	31.3	86.1	67.1	13.8	17.6	3.2	37.4	52.9	67.2	126.1	85.5	663.8
	Average °C	16.6	14.6	10.6	7.0	0.9	1.5	5.4	8.8	9.2	15.5	18.2	19.2	
1976	Min.	7.5	4.5	- 2.0	3.5	-16.0	-17.0	-10.5	- 4.5	2.0	2.5	3.0	9.5	
1977	Max.	26.0	28.0	26.0	19.0	13.0	13.0	19.5	26.0	27.0	28.0	31.5	30.0	
	Precipitation/mm	95.1	87.9	69.7	41.7	100.3	69.6	69.6	26.5	46.7	83.0	95.4	99.6	885.1
	Average °C	19.1	13.4	11.4	6.1	- 1.5	0.0	0.0	6.9	9.6	13.4	17.6	19.0	
1977	Min.	7.5	- 0.5	- 0.5	- 5.2	-17.5	- 9.5	-22.0	- 3.5	- 0.5	- 1.5	9.0	6.8	
1978	Max.	29.5	28.0	24.5	22.5	11.0	9.5	14.0	21.0	23.0	22.0	28.5	31.0	
	Precipitation/mm	34.6	49.0	34.2	79.3	73.0	30.0	56.3	50.8	42.5	66.5	73.5	71.3	661.0
	Average °C	18.8	14.9	10.0	1.3	1.9	1.7	2.3	8.5	9.4	16.6	19.9	17.1	
1978	Min.	7.0	3.0	- 1.0	- 4.5	-11.0	-15.0	- 5.8	- 6.5	- 1.0	- 1.0	10.0	9.5	
1979	Max.	32.0	29.0	23.5	12.5	13.6	16.0	14.2	21.5	21.0	28.5	30.5	32.0	
	Precipitation/mm	50.7	42.7	15.8	19.5	59.2	90.7	74.9	47.1	53.1	4.9	65.7	122.5	648.8

region was considerably larger in this period amounting to 5.95 q/ha or 11.87%. The trend of yield increase was only 0.51 q/ha.

Conclusions

On the basis of this analysis the following conclusions can be made:

It is clear that climatic factors had an influence on wheat yield.--They limited the yield and were present in all the plots.

The difference in yields in different plots and between varieties depended on other factors. The parallel data of the average and maximal yields in PPK Kutjevo confirm this statement.

Yields	Year 1975	1976	1977	1978	1979	Av. X	Index	Std. dev.	Co. var. V %	Trend q/ha
Av.	45.4	57.4	50.3	52.0	55.0	52.02	100	4.11	7.91	1.38
Max.	59.8	78.5	73.8	73.8	68.4	70.86	136	6.39	9.01	1.25

The average maximal yield in a five-year period from 1975-1979 amounted to 70.86 q/ha with standard deviation of 6.39 q/ha and coefficient of variation 9.01%. The trend of yield increase amounted to 1.25 q/ha. Compared with average yield, maximal yield is 36% higher, but with decreased trend and increased coefficient of variation.

The variety has also a considerable influence on the wheat yields.--In the period of five analyzed years "Zlatna dolina" occupied 70.94% of sown area and contributed with its high yields to the realization of an average yield of 52.02 q/ha. All the maximal yields in this period, averaging 70.86 q/ha on certain plots, were obtained with "Zlatna dolina". With regard to the obtained average maximal yield, these production results indicate that the yield capacity of the variety has been exploited with 71% approximately. Subject to the melioration and the yield tendency of increasing by 1.38-1.25 q/ha, it may be possible to exploit the genetic potential of "Zlatna dolina" in the agro-ecological circumstances of PPK Kutjevo even by 90%, which means that a yield of 85-90 q/ha could be realized.

The quality of primary and secondary tillage as well as sowing in the conditions of this soil and climate, have a special influence on wheat yield. Sowing performed too early, or too late, has an influence on the yield depending on the variety and tillering capacity.

The size of seed, correct application of mineral fertilizers, agro-technique adaptation to the variety requirements, diseases and pests, unfavorable arrangement of precipitation, high and low temperatures in the vegetative periods, as well as many other factors, have a significant influence on the components of yield.

The above indicates that two groups of factors can be established. The first group includes climatic factors which cannot be influenced and which limit the production. The other group include agrotechniques and variety and soil, which can be influenced. This fact, as well as the correct application of agro-technique measures, selection of variety, soil preparation, etc. can serve to correct exploiting the genetic potential of the variety and approaching the realized maximal yield as much as possible.

DISEASE PROBLEMS OF RAINFED WHEAT

E. E. Saari and J. M. Prescott
CIMMYT, Cairo, Egypt and Ankara, Turkey

Abstract

Wheat diseases most often encountered in the semi-arid regions are closely associated with soil and seed. The farming system and the rotations practiced also strongly influence the disease cycles. Foliar diseases are present but they are not as dominant as in more favorable environments. This is a direct reflection of the lack of free water required by the foliar pathogens for the infection process. If moisture is available, either in the form of rain or dew, the foliar diseases can develop to serious levels.

The data base for losses caused by diseases in the semi-arid areas is meager. Losses may be relatively small, but if calculated as a percentage of the total yield they can be significant.

A number of local wheat cultivars have been screened over a wide range of environments in recent years. They are tall with low yield potentials but stable under moisture stress situations. When grown in areas where moisture is not as limiting, the foliar diseases are usually severe on these cultivars, and they are in most instances highly susceptible to the wheat rust diseases.

In the area of West Asia and the Mediterranean basin where semi-arid conditions are frequently encountered, the climate is typified by a warm, dry summer and a cool, rain period during the winter. The practice of annual wheat cropping is common, and a fallow system is practiced in the lower rainfall zones. This type of single crop system and the environment favors soil-borne pathogens, which can survive from one season or crop to the next.

The teliospores of the bunt fungus, *Tilletia spp.*, survive either in the soil or on the seed. If a susceptible variety is grown and chemical seed treatment is not practiced, the bunt diseases are probably the most important disease under semi-arid conditions. The widespread nature and seriousness of these diseases are not fully appreciated. The long term association of the bunt diseases in semi-arid conditions has also placed a strong selection pressure on the host. From these areas the major sources of bunt resistance are to be found.

Other important diseases encountered are the root rots caused by *Fusarium spp.* and *Helminthosporium spp.* The Take-All disease caused by *Gaeumannomyces graminis* and Eye Spot caused by *Pseudcosporella herpotrichoides* are serious problems in some areas. The flag smut fungus, (*Urocystis agropyri*), and partial bunt caused by *Nevossia indica* can become important in areas where highly susceptible cultivars are introduced.

Foliar and spike diseases become increasingly more important when the rainfall begins to exceed 500mm. The frequency and distribution of the rain throughout the season also is critical. The most common diseases in the higher rainfall areas are leaf rust (Puccinia recondita), yellow rust (P. striiformis), stem rust (P. graminis), Septoria tritici, Helminthosporium tritici repentis and powdery mildew (Erysiphe graminis). The loose smut fungus (Ustilago tritici) is a persistent disease in most environments, but the build-up of this disease is favored when cool, more humid, conditions prevail at flowering time.

Other diseases are present but they are usually of local importance. The viruses seem to be limited, due either to low vector or virus survival during the off-season. Aphids, however, are being recognized as an increasing problem in some areas. Nematodes have been recorded but only Heterodera avenae has been identified as a serious problem in some farm fields.

Wheat is one of the oldest and most important food crops in the world. It is the major food grain cereal in total production. A large international trade is conducted in wheat (See table 1). The International Maize and Wheat Improvement Center (CIMMYT), Mexico, is concerned with assisting the developing countries in their wheat production efforts. We are concerned with increasing production and with the stability of production. CIMMYT attempts to assist the developing nations through the training of scientists and through the development of germplasm. The main characteristics incorporated into the germplasm are high yielding potential, wide adaptability, and resistance to stress and diseases.

Table 1: Estimated Wheat Production in 1978 and Trade in the year of 1978-79. (Adapted from Report of the International Wheat Council, London, England 26 July, 1979).

Region	Production (millions tons)	Trade Imports (millions tons)
Western Europe	63.8	6.7
Eastern Europe	30.6	4.5
U.S.S.R.	120.8	4.5
North & Central America	72.8	3.0
South America	12.2	7.8
Asia	113.7	31.6
Africa	9.4	12.4
Oceania	18.9	-
Other unspecified	-	0.5
TOTAL	442.2	71.0

If climate and soil are suitable for wheat cultivation, the most important factor affecting stability is drought. CIMMYT has been concerned and is attempting to develop germplasm which will be stable under drought conditions. Once the factor of drought

is eliminated and moisture levels are adequate, the biological factors most important to wheat production are the diseases, insects, weeds and, on occasion, animals and birds.

Fortunately, the insects are not as serious a problem as they are in other crops. There is, never-the-less, a diversity of insects which attack wheat which can occasionally become a production problem. Because insects are sporadic in occurrence there has been relatively little done in the area of breeding for resistance. When insect infestations do occur, they are usually serious because of the lack of preparation for alternative control procedures. The insects most often observed and reported on wheat in Africa and Asia are given in tables 2 and 3.

Table 2: Insects identified as causing damage to wheat in Africa and the Middle East and some of the genera recorded.

Ants	Leaf roller
Several	Cnephasia
Aphids	Locust
Macrosiphum	Schistocerca
Rhopalosiphum	Locusta
Schizaphis	Sawfly
Armyworm	Cephus
Spodoptera	Scales
Beetles	Porphyrophora
Zabrus	Shoot fly
Heteronychus	Atherigona
Cereal leaf beetle	Stinkbugs (Cinch/
Oulema	Senn/Shieldbug)
Hessian fly	Aelia
Mayetiola	Eurygaster
Grasshoppers	White grubs
Several	Malclontha
Ground pearl	Anisoplia
Margarodes	Wireworms (cutworm)
Leaf miner	Agrotis
Syringopais	

Table 3: Insects identified as causing damage to wheat in South and Southeast Asia and some of the genera.

Aphids	Jassids
Macorsiphum	Empoasca
Myzus	Leaf hopper
Rhopalosiphum	Pyrilla
Schizaphis	Mite
Armyworms	Petrobia
Cirphis	Aceria
Heliothis	Pod-borer
Prodenia	Heliothus
Pseudabetia	Sawfly
Mythimna	Cephus
Cutworms	Shoot-fly
Agrotis	Atherigona
Cirphis	Stemborer
Euxoa	Sesamia
Flea beetle	Termites
Chaetocnema	Odontotermes
Grasshoppers	Microtermes
Chrotogonus	Wheat weevel
Typhlocyba	Tanymecus
	Wireworm
	Agriotes
	Melantous

Weeds are a very important problem. In the higher rainfall areas where labor is scarce and handweeding cannot be exercised weeds can be a major production constraint. Many species of weeds affect the wheat crop. The most commonly reported are listed in table 4.

Table 4: The broadleaf and grassy weeds most commonly reported as important to wheat production in Africa and Asia.

Broadleaf genus/species:	
Alhagi maurorum	*Lamium* spp.
Ammi majus	*Lathyrus* spp.
Anthemis spp.	*Leontice* spp.
Boreava orientalis	*Malva* spp.
Brassica spp.	*Matricaria* spp.
Capsella bursa-pastoris	*Medicago* spp.
Cardaria draba	*Melitotus* spp.
Carthamus oxyancanthus	*Nicandra* spp.
Centaurea spp.	*Polygonum aviculare*
Chenopodium spp.	*Ranunculus arvensis*
Chephalaria syrica	*Raphanus* spp.
Cirsium acarna	*Scandix* spp.
Convolvulus arvensis	*Silene* spp.
Euphorbia spp.	*Sinapis* spp.
Fumaria spp.	*Spergula* spp.
Galium spp.	*Vicia* spp.
Glycyrrhiza glabra	

Grass genus/species:

Avena spp.	*Lolium* spp.
Aegilops spp.	*Penisetum* spp.
Bromus spp.	*Phalaris* spp.
Cynodon dactylon	*Seteria* spp.
Cyperus rotundus	*Snowdenia polystachya*
Hordeum spp.	

Animals and birds are an issue in some areas. The Quelea bird is a major problem in East Africa. Rats are considered to be an important problem in all of the wheat growing areas of the world. In certain regions moles can be a serious pest. Depending upon the area, the extent of destruction by higher animals varies.

The diseases of wheat are the most consistent and important factors affecting wheat production. Because of the widespread nature of the various diseases, CIMMYT has placed a great deal of emphasis on breeding for resistance.

The pests that have been mentioned affect yield but the extent depends upon the location and prevailing weather conditions. The average yields in Asia and Africa are relatively low compared to North America and Europe (See table 5). This is partially a reflection of the unfavorable environment that exists in much of the area. The precipitation ranges from less than 250 mm to over 1000 mm in the agricultural areas. The lower yields, however, also reflect the importance of diseases, insects and weeds.

Table 5: Wheat area, production and yield.
(Source: FAO Production Yearbook 1977).

Region	Area 1000 ha	Production 1000 MT	Yield Kg/ha.
Africa	8555	8217	960
Asia	31501	40003	1387
Europe	24819	82325	3317
North America	37687	77281	2051
WORLD	232382	386596	1664

There are few estimates of losses caused by the various pests. The most comprehensive review on losses was done by Cramer in 1967, and the loss due to pests in Asia and Africa was placed at 27 and 39 percent respectively (See table 6). These figures were considered conservative at the time they were published. There have been extensive changes in wheat production since then, and these values have undoubtedly changed.

Table 6: Estimated losses caused by diseases, insects and weeds to wheat production in Asia and Africa. (Calculations based on losses from potential production - from Cramer 1967).

	Calculated percentage loss in production due to:			
Region	Insects	Diseases	Weeds	Total
North America	4.9	11.5	9.0	25.4
South America	4.0	13.0	10.0	27.0
Oceania	4.9	11.5	9.0	25.4
Europe*	4.7	5.4	9.6	19.7
Africa	12.0	12.0	15.0	39.0
Asia**	5.0	12.0	10.0	27.0
U.S.S.R.	5.0	9.0	10.0	24.0
P.R. China	5.0	9.0	10.0	24.0
TOTAL	5.0	9.1	9.8	23.9

* Excludes USSR
** Excludes USSR and P.R. China

Weeds are considered a major problem particularly in Africa. A number of experiments on weed control have been done in the Middle East and North Africa since 1967. In table 7 a summary is presented of the losses reported by various researchers. The losses in South and Southeast Asia vary, but the intensive crop rotations and the practice of hand weeding reduces the significance of weeds.

Table 7: Estimated losses in wheat production caused by weeds.

Source	Year	Area	Range of losses %
Cramer	1967	Africa and	15
		Asia	10
Saghir and Aqiqullah	1970	Lebanon	17
Al-Qaisi	1972	Iraq	45
Parker and Fryer	1975	World	11.5
Aresvik	1976	Jordan	30-60
Hepworth and Tezel	1976	Turkey	20
Nelson	1976	North Africa and Middle East	19.4
AICWIP	1978	India	8-13
Nelson	1978	Algeria	11-67
Saghir	1978	Near East	20-30
Basler	1979	Algeria	50-60
		Egypt	10
		Syria	20
Ladada	1979	Algeria	30-60

The losses from insects have not been as well documented and this is partly a reflection of the sporadic nature of insects. The research in entomology has been more descriptive rather than analytical in most instances.

In the rainfed areas the diseases must be considered a major problem and a factor in wheat production. This is reflected by the fact that they are present to some degree almost every year. Their relative importance will be determined by the commercial variety being grown and the prevailing weather. Another reflection on the importance of the diseases can be seen from the reports from CIMMYT nurseries (See table 8). There were no insect infestations recorded in the reports analyzed. Leaf rust (*Puccinia recondita*) was the most frequently reported disease. Yellow rust (*P. striiformis*) and stem rust (*P. graminis*) were reported next most frequently. The only other diseases mentioned were Septoria blight (*Septoria tritici*) and powdery mildew (*Erysiphe graminis*).

Table 8: Summary of the wheat diseases reported in the International Spring Wheat Yield Nursery (ISWYN) 1973 to 1977 and the International Durum Yield Nursery (IDYN) 1969 to 1977 from the Middle East and North Africa (From Saari, Prescott and Kamel 1979).

	Middle East		North Africa	
Disease	ISWYN	IDYN	ISWYN	IDYN
Leaf rust	24	7	6	6
Yellow rust	12	8	0	5
Stem rust	10	6	4	1
Septoria tritici	9	0	0	0
Powdery Mildew	3	1	0	0
Total Nurseries Reporting	37	34	20	19

The three rusts continue to be our major problem because of the tremendous losses they cause when they become epidemic or pandemic. This ability to become epidemic in a very short period plus the ability of the fungus to change and attack resistant varieties perpetuates the rust diseases as the most important despite extensive efforts in breeding for resistance. Even in the dry areas when rainfall is above normal the rust diseases increase in importance. Often when a bumper crop is anticipated because of favorable moisture, the rusts will negate this unless a resistant variety is being cultivated.

Based on nursery reports Septoria blight has been the fourth most recorded disease. Septoria blight tends to be more important in areas where rainfall is in excess of 600 mm. This disease is found throughout North Africa, in parts of the Middle East and in the East African highlands. In the areas having a Mediterranean type climate, the fungus survives from one season to the next on straw. The common practice of mono-culturing of wheat also favors Septoria development. When the rainfall falls below 600 mm the wet periods are usually too short or infrequent for a serious Septoria epidemic. If wheat is rotated with other crops, the residue is reduced and decreases the impact of Septoria. In irrigated areas Septoria blight is seldom a problem because of the rotations practiced. In serious epidemics losses can be up to 50 percent and in a few cases complete crop failure has been recorded. We do not have good values for the over-all losses caused by Septoria.

Powdery mildew is found in many areas but in the lower rainfall areas it is seldom a serious problem. The losses caused by powdery mildew are difficult to document. This is possibly a reflection of the disease cycle. Infection usually takes place in the spring as plants are rapidly growing. This shortens the time for the host-parasite interaction and may be the reason losses from mildew are not readily apparent. Seldom we do find spike infections of powdery mildew in the rainfed areas and this would also minimize the damage done by this disease.

The foliar disease Tan Spot, caused by Helminthosporium tritici-repentis (Pyrenophora trichostoma) is widespread and common. Its importance has only recently been recognized although it has been present for a long time. It can cause serious losses to wheat even under rainfed conditions. Tan Spot can cause complete defoliation, but we do not have judgements as to how much damage it causes.

The practices of mono-culturing wheat and wheat-fallow-wheat where rainfall is low has a tendency to build up the soilborne pathogens. Take-all is a soil-borne disease which is widespread throughout the rainfed wheat growing areas. It is seldom epidemic but is found attacking individual plants, and on occasion, rather large areas in a field. It can be reduced by crop rotations. We do not have valid figures regarding the importance of Take-all.

Another important disease in rainfed areas in Fusarium root rot, (Giberella zeae and Fusarium spp.) and the spike infection phase referred to as Scab. The Scab phase can be serious because it affects the developing kernels, and toxins can be produced which may make it unfit for human or animal consumption. The root rot caused by Fusarium is sporadic and patchy in fields. The practice of mono-culturing also increases the seriousness of this disease. We do not have estimates on the losses caused by Fusarium.

Pseudocerocosporella Eye Spot, the soil-borne pathogen, is severe in those areas where wheat is in continuous cultivation and the cool winters favor development. It tends to be restricted to the more morthern latitudes or higher elevations where wheat is cultivated.

The smuts and bunts are probably the most under-rated diseases in Asia and Africa, particularly in the rainfed regions. In the areas where you have winter rainfall and dry summers, bunt (Tilletia spp.) survives in the soil and on the seed as a contaminant. Because of an inadequate seed industry in most countries, and the lack of seed treatment, bunt can be found throughout much of the area. We do not have estimates as to the losses caused but our observations force us to rank it as the number one problem in the winter wheat growing areas and at the higher elevations if susceptible varieties are cultivated. For example, in the remote areas resistant varieties and seed treatments are often unavailable, we have observed fields with 50 percent of the spikes infected. Until either resistant varieties or the practice of

seed treatment is well established this disease will probably continue to be the number one problem in the areas where it is established.

Loose smut (Ustilago tritici) is a common and chronic disease and it is often underestimated. It will establish an equilibrium depending on the variety. When a susceptible variety is grown, the number of infected spikes can become quite high. We have observed in some of the mountainous areas, where the infection period is more favorable, fields with 30 percent loose smut. In the dryer areas the loose smut percentages are lower but one can usually find loose smut in the susceptible varieties at levels between 1-10 percent.

Flag smut (Urocystis agropyri) is restricted to the rainfed areas throughout the area. The spores can survive in the soil for extended periods or as contaminants on the seed. When a susceptible variety is cultivated this disease can increase significantly. In the rainfed area of northern Pakistan a susceptible variety was introduced and the disease increased significantly. In a survey done in 1976 the percentage of infected plants per field varied between 2 to 33 percent with an average of 12 percent in the Rawalpindi area. We do not have figures for the over-all total loss that flag smut causes, but it is probably a relatively minor disease in most of the rainfed areas. Resistant varieties are effective in controlling the disease and the resistance is stable.

A new problem in the irrigated and rainfed areas of northern India, Pakistan and parts of Afghanistan is partial or Karnal bunt (Neovossia indica). This is a rather unique disease with the spores surviving in the soil or as contaminants on the seed. The spores germinate at flowering time and infection causes a partial bunting. This disease has been considered minor, but in 1978 and 1979 it increased to such levels that it became a cause for concern. The number of fields in North India with Karnal bunt increased, and in 1979 ten to eighty percent of the seed samples collected from the northern states contained bunted seeds. The percentage of infected kernels in each sample varied from 0 to 33 percent. The reason for the increase is unknown but probably reflects the release of varieties highly susceptible to this pathogen, and unusually favorable weather for the infection process.

Several virus diseases are found throughout the region. They have not been seen in epidemic proportions. The probable reasons are the lack of survival of the virus in reservoir plants and the low survival of the insect vector from season to season.

There is, however, an increasing awareness of the presence and effects of aphids. The reason for this shift cannot be explained. The aphids themselves are now being recognized as a serious problem in some areas. The increase in aphids will undoubtedly result in a greater amount of barley yellow dwarf virus. The situation bears watching. Several other viruses are

also recorded. They have been observed on scattered, individual plants and have not been considered to be of economic importance.

The important nematode diseases of wheat are relatively few. The gall nematode (Anguina tritici) is found in fields sown to older varieties, but this problem can be readily corrected by the use of clean seed. The most serious nematode problem is the cyst nematode (Heterodera avenae). Once it is established in a field losses can be quite serious, particularly in barley. It is increasing and still confined to isolated fields. We do not have loss estimates, but it probably does not affect over-all production greatly.

The bacterial diseases caused by Xanthamonas translucens and Pseudomonas spp. have been recorded. They have not been regarded as economically important in the farm fields.

We have no good estimates for the losses caused by an individual disease, so consequently it would be difficult to place a judgment on the damage done from the diseases collectively. We do know, however, that they are important and that in certain circumstances losses can be substantial. Partially due to the variability and extensive nature of wheat cultivation we will continue to be dependent upon resistant varieties for the control of the diseases. In table 9 we have listed the diseases that we consider to be the most important at this time based on our experiences. We will continue to give priority to these diseases in our efforts to develop resistant germplasm.

Table 9: The wheat diseases considered to be the most serious in Asia and Africa at the present time.

Leaf rust
Yellow rust
Stem rust
Bunt (Tilletia spp.)
Septoria blight
Helminthosporium spp.
Root rots
Loose smut
Powdery mildew

References

Annual Report 1977-78. Weed control research section. The International Center for Agricultural Research in Dry Areas (ICARDA), Aleppo, Syria. 52 pp.

Anonymous 1975. Wheat production in the Kingdom of Saudia Arabia. pg. 355-360. In Proc. Third Regional Wheat Workshop, Tunis, Tunisa. CIMMYT, Mexico 388 pp.

Ba-Angood, S.AS. 1975. Wheat Improvement in the Peoples Democratic Republic of Yemen. pg. 352-354. In Proc. Third Regional Wheat Workshop, Tunis, Tunisa. CIMMYT, Mexico. 388 p.

Bhardwaj, R. B. L. 1978. New agronomic practices. pg. 79-98. In Wheat Research in India 1966-1976. Indian Coun. of Agric. Res. New Delhi 244 pp.

Bhatia, S.D. 1978. Insect pests pg. 152-167. In Wheat Research in India 1966-1976. Indian Coun. of Agric. Res., New Delhi, 244 pp.

Chaudhry, G.Q. 1978. Plant protection for field food crops on small holdings in Pakistan pg. 254-258. In Technology for Increasing Food Production. J.C. Holmes (ed). FAO-TFINT 285, Rome. 695 pp.

Chiang, H.C. 1977. Pest management in the People's Republic of China-monitoring and forecasting insect population in rice, wheat, cotton and maize. FAO Plant Prot. Bull. 25: 1-7.

Cormack, M.W. 1974. Wheat diseases in Kenya. pg. 306-308. In Proc. Fourth FAO/Rockefeller Foundation Wheat Seminar, Tehran, Iran. FAO Rome. 441 pp.

Cramer, H.H. 1967. Plant protection and world crop production. Pflanzenochutz Nachrichten Bayer 20: 1-524.

Djerbi, M. and Ghodbane, A., 1976. Essais de Lutte contre La Septoriose due Ble (Septoria tritici Rob. Et Desm.) pg. 143-147. Poljoprivredna Znanstvena Smotra, Agriculturae Conspecturs Scientificus YU ISSN 0370-0291 39 (49), Zagreb.

Gebeyhou, G. 1975. Durum wheat production and research in Ethiopia. pg. 341-344. In Proc. Third Regional Wheat Workshop, Tunis, Tunisa. CIMMYT, Mexico. 388 pp.

Handbook on Crop Production in Ethiopia (1st Edition) 1979. Institute of Agric. Res., Addis ababa. 41 pp.

Hassan, S.F. 1974. Wheat diseases and their relevance to improvement and production in Pakistan. pg. 284-286. In Proc. Fourth FAO/Rockefeller Foundation Wheat Seminar, Tehran, Iran. 441 pp.

Hepworth, H.M. and Tezel, C. 1976. Weed control on the high plateau of Turkey. In Proceedings of the Third Regional Wheat Workshop, Tunis 1975. pg. 186-191. CIMMYT, Mexico. 388 pp.

Hussain, S.M. and M.H. KASIM. Weeds and their control in Iraq. PANS 22: 399-404.

Insect Control in the Republic of China. 1977. CSCPRC Report No. 2 Nat. Acad. of Sci., Wash. D.C. 218 pp.

International Maize and Wheat Improvement Center. 1977 CIMMYT. Report on Wheat Improvement 1976. El Batan, Mexico, 234 pp.

International Maize and Wheat Improvement Center. 1978. CIMMYT. Report on Wheat Improvement 1977. El Batan, Mexico. 245 pp.

International Wheat Council Reports. 1978 and 1979. Haymarket House, London, England

Javaid, I. and M. Ashraf. 1977. Wheat Diseases in Zambia, 1973-1976. Plant Dis. Rep. 61: 953-954.

Johnson, V.A. and H.L. Beemer, Jr. 1977. Wheat in the People's Republic of China. CSCPRC Report No. 6 Nat. Acad. Sci., Wash. C.C. 190 pp.

Joshi, L.M., K.D. Srivastava, S. Nagarajan and C.V. Singh. 1979. Wheat Disease Newsletter 1978-79. Indian Agriculture Research Institute, New Delhi. 121 pp.

Joshi, L.M., K.D. Srivastava, D.V. Singh, L.B. Goel and S. Nagarajan. 1978. Annotated Compendium of Wheat Diseases in India. Indian Coun. Agri. Res., New Delhi. 332 pp.

Kauweider, A.K. and M. Al-Hamawi. 1975. Durum wheat in Syria. pg. 361-366. In Proc. Third Regional Wheat Workshop, Tunis, Tunisa. CIMMYT, Mexico 388 pp.

Kelman, A. and R.J. Cook. 1977. Plant pathology in the People's Republic of China. Ann. Rev. Phytopath. 17: 409-420.

Khazra, H. and A. Bamdadian. 1974. The wheat diseases situation in Iran. In Proceedings of the Fourth FAO/Rockefeller Foundation Wheat Seminar, Tehran, Iran 21 May- 2 June 1973. pg. 292-299. Food and Agriculture Organization of the United Nations. Rome. 441 pp.

Kidwai, A. 1977. Pakistan Reorganizes Agriculture Research after Harvest Disaster. Nature 277: 169.

Koehler, C.S., R.D. Wilcosxon, W.F. Mai, and R.L. Zindahl. 1972. Plant Protection in Turkey, Iran,Afghanistan, and Pakistan. U.S. Agency for International Development- Univ. Calif. Berkeley.Contract No. AID/csd- 3296. 82 pp.

Kranj, J., H.S. Schmutterer and W. Koch. 1977. Diseases, Pests and Weeds in Tropical Crops. Verlag Paul Parey, Berlin and Hamburg. 666 pp.

Maladies Et Ravagewrs Des Plantes Cultivess Au Maroc Tome 1. 1976. Ministere de L'Agriculture et de la Reforme Agraire. Direction de La Recherche Agronomomuque, Rabat. 207 pp.

Melifronides, I.D. 1977. The cereal leaf miner, Syringopais temperatella, and its control in Cyprus. PANS, Vol. 23 No. 3. pg. 268-271.

Nelson, W. 1976. The weed situation in the regions of North Africa and the Middle East. pg. 178-183. In Proc. Third Regional Wheat Workshop, Tunis, Tunisia. CIMMYT, Mexico. 388 pp.

Parker, C. and J.D. Fryer. 1975. Weed control problems causing major reductions in the world food supplies. FAO Plant Prot. Bull. 23: 83-95.

Prescott, J.M. and E.E. Saari. 1975. Major disease problems of durum wheat and their distribution within the region. pg. 104-114. In Proc. Third Regional Wheat Workshop. Tunis, Tunisia. CIMMYT, Mexico. 388 pp.

Qureshi, J. 1978. Seed industry project. pg. 125-129. In Wheat Research and Production in Pakistan. M. Tahir (ed.). Pakistan Agric. Res. Coun., Islamabad. 227 pp.

Ram, B. and L.M. Joshi. 1978. Spray schedule of Fytolan for leaf blight of wheat and its effect on yield components. Indian Phytopathology. Vol. 31 pg. 348-351.

Rao, M.V. 1978. Wheat in India: an overview. pg. 1-10. In Wheat Research in India 1966-1976. Indian Coun. of Agric. Res., New Delhi. 244 pp.

Report of the Coordinated Experiments Wheat Agronomy 1977-78. All India Coordinated Wheat Imp. project. Indian Coun. Agric. Res., New Delhi, 167 pp.

Roelfs, A.P. 1977. Foliar fungal diseases of wheat in the People's Republic of China. Plant Dis. Rep. 61: 836-841.

Roy, J.L.H. and J.S. Gill. 1977. FAO Desert locust programme. FAO Plant Prot. Bull. 25: 167-170.

Saari E.E. 1978. Survey of Wheat Diseases in Southern Spain. Mimeographed Report to Sevico de Defensa Contra Plagas e Inspeccion Fitopatologica, Ministeria de Agriculture, Madrid. 11 pp.

Saari E.E., J.M. Prescott and A.H. Kamel. 1979. The significance of diseases and insects in cereal production. Proceedings of Fifth Regional Cereal Workshop, Algers, Algeria, Inpress. CIMMYT, Mexico.

Saari, E.E. and J.P. Srivastava. 1977. Improved and stabilization of production of winter cereals: Potentials in a single-crop system. Mimeographed paper. The Midile East and Africa Agric. Seminar, Tunis. Tunisia. Feb. 1-31, 1977. The Ford Foundation, New York, 34 pp.

Saari, E.E. and R. D. Wilcosxon. 1974. Plant disease situation of high-yielding dwarf wheats in Asia and Africa. Ann. Rev. Phytopath. 12: 49-68.

Saeed, S.A. 1978. Weeds and weed control in wheat. pg. 103-107. In Wheat Research and Production in Pakistan. M.Tahir (ed.). Pakistan Agri. Res. Coun., Islamabad. 227 pp.

Saghir, A.R. 1978. Weed control in wheat and barley in the Middle East. pg. 300-308. In Barley Vol. II: Proc. Fourth Regional Winter Cereals Workshop, Amman, Jordan, 24-28 April 1977. ICARDA-CIMMYT, Aleppo, Syria 420 pp.

Saghir, A.R. 1977. Weed control in wheat and barley in the Middle East, pg. 282-285. PANS, Vol. 23 No. 3.

Sanchez, F.F. 1975. Rodents affecting food supplies in developing countries: problems and needs. FAO Plant Prot. Bull. 23:96-102.

Schulter, D. and A. Janati. 1976. Les Septorioses du Ble au Maroc. pg. 7-13. Phytopathologia Mediterranea, Volume XV-N.1.

Sharif, G. and A. Bamdadian. 1974. Importance and situation of wheat and barley diseases in Iran. In Proceedings of the Fourth FAO/Rockefeller Foundation Wheat Seminar, Tehran, Iran. 21 May 2-June, 1973. pg. 300-305 Food and Agriculture Organization of the United Nations. Rome. 441 pp.

Sheshadri, A.R. and C.L. Sethi. 1978. Nematode problems, pg. 169-187. In Wheat Research in India 1966-1976. Indian Coun. of Agric. Res., New Delhi. 244 pp.

Walker, P.T. 1975. Pest control problems (pre-harvest) causing major losses in world food supplies. FAO Plant Prot. Bull. 23: 70-77.

Yuksel, M. 1970. Field pests of the wheat crop in Turkey. pg. 259-260. Proceedings Third FAO/Rockefeller Foundation Wheat Seminar, Ankara, Turkey.

POSTULATION OF GENES FOR STEM RUST RESISTANCE IN THE INTERNATIONAL WINTER WHEAT PERFORMANCE NURSERY I THROUGH XI

D. V. McVey
United States

Abstract

The presence of gene(s) for resistance to stem rust (*Puccinia graminis* Pers. f. sp. *tritici* Eriks. & E. Henn.) in wheat (*Triticum aestivum* L. em. Thell.) was detected in entries of the International Winter Wheat Performance Nurseries I through XI by use of 28 isolates of stem rust previously characterized for virulence on 25 genes. Seventeen genes were postulated as being present. A few cultivars possessed genes for stem rust resistance other than those studied. No genes for resistance were detected in 16 cultivars, one gene was detected in 66 cultivars, two genes in 28, three genes in 19, and four and five genes each in two cultivars. Genes for stem rust resistance *Sr5*, McN, 17, and 8 were most commonly postulated, whereas *Sr9e*, 13, 14, 15, 16, 25, 26, and 27 were not detected in any of the entries.

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The International Winter Wheat Performance Nursery (9) was organized in 1968 by the Nebraska Agricultural Experiment Station and the Agricultural Research Service, U.S. Department of Agriculture, under a contract with the Agency for International Development, U.S. Department of State.

These wheats (*Triticum aestivum* L. em. Thell.) offered an opportunity to compare the presence and distribution of genes for resistance to stem rust (*Puccinia graminis* Pers. f. sp. *tritici* Eriks. & E. Henn.) in cultivars from a wide geographical area. Therefore, these wheats were tested for the presence of stem rust resistance genes *Sr5*, 6, 7b, 8, 9a, 9b, 9d, 9e, 10, 11, 12, 13, 14, 15, 16, 17, 24, 25, 26, 27, 29, 31, McN, Tmp, and Tt-1. Based upon the gene-for-gene concept (1), the presence of a specific resistance gene(s) in the host can be demonstrated with suitable combinations of genes for avirulence and virulence in the pathogen (5, 6).

Materials and Methods

Entries of the International Winter Wheat Performance Nurseries I through XI were tested for seedling reaction to 28 isolates of stem rust (Table 1). Each isolate possesses a different combination of genes for virulence. This diversity is shown by the standard race numbers and the Cereal Rust Laboratory code. These isolates are in liquid nitrogen storage and are available for further studies. The 25 monogenic lines for stem rust resistance upon which the selection of isolates was made, their

Cereal Rust Laboratory, U.S. Department of Agriculture, SEA-AR, St. Paul.

Table 1. Test cultures of *Puccinia graminis* f. sp. *tritici* used to identify genes for resistance in the entries of International Winter Wheat Performance Nurseries I through XI.

Culture No.	Identification No.	Race designation Standard	Race designation CRL[a]
1	72-00-53A	32	RTQQ
2	72-45-1212B	Near 83	SBCS
3	72-21-1184B	15	TBMH
4	73-21-848B	15	TDMH
5	65-39-20	15	TLMH
6	Bugby	15	TMMT
7	72-41-140A	15	TMRT
8	72-4-1A	15	TNMH
9	74-21-1409A	15	TNMK
10	68-41-73A	17	HNLQ
11	72-45-1095A	Near 102	LBCN
12	70-BB-458A	23	LCBN
13	72-45-1212A	23	LFCN
14	59-14-19	56	MBCT
15	72-45-855C	Near 51	PBCS
16	72-00-1370C	151	QFBS
17	69-21-399	151	QSHS
18	71-21-550C	32	RHMS
19	71-21-584B	11	RHRS
20	70-11-98B	32	RKQQ
21	72-25-639C	32	RKQS
22	72-14-504C	32	RPQQ
23	72-18-630B	32	RSHS
24	73-45-399C	Near 59	BFCN
25	75-45-1622A	Near 211	DKCS
26	72-45-1080C	Near 102	GLCN
27	72-21-1173C	17	HDLQ
28	70-44-64A	29	HJCS

[a] Cereal Rust Laboratory code.

source, background variety, and low infection type (IT) are given in Table 2 (7). The line W3499 has Sr13 in addition to recessive gene Sr17 (3), the cultivar Etiole de Choisy (PI 193108) has Sr23 in addition to Sr29 (3), and the cultivar Aurora has Sr5 in addition to Sr31. The low IT of the selected isolates on the monogenic lines are presented in Table 3.

The presence of gene(s) for resistance to stem rust was postulated (4) by use of a slight variation of the visual analysis method outlined by Loegering, et al. (2). In this procedure, the avirulence or virulence of an isolate for the resistance of each tested Sr gene was determined by the IT on monogenic lines. This determination defined an avirulence/virulence formula for each isolate. Then the gene(s) in a test cultivar were deduced as present or absent by the IT of each host-isolate interaction. For

Table 2. The source, background, and expressed infection type of the monogenic Sr lines used in selection of isolates of *Puccinia graminis* f. sp. *tritici*.

Sr gene	Monogene line	Source	Background	Low infection type[a]
5	CI 14159	W. Q. Loegering	CS[b]	0 to 0;
6	CI 14163	W. Q. Loegering	CS	;
7a	Line G	Univ. of Sydney	Mendos/W2691// W3498	23C
7b	CI 14165	W. Q. Loegering	CS	2^{+}
8	CI 14167	W. Q. Loegering	CS	2
9a	CI 14169	W. Q. Loegering	CS	2,32
9b	Line AA	I. A. Watson	W2691[c]	2^{+}
9d	CI 14177	W. Q. Loegering	CS	;2^{-}
9e	W 3196	I. A. Watson	Vernstein	; to $2^{=}$
10	CI 17388	A. P. Roelfs	W2691	;1N to XN
11	CI 14171	W. Q. Loegering	CS	;,2
12	CI 17783	A. P. Roelfs	BtSr12Tc (Baart/Line R)	0;1^{+}
13	CI 17387	A. P. Roelfs	W2691	2^{+}3
14	Line A sel	Univ. of Sydney		23C
15		Australian cultivar	Norka	;1+N to XCN
16	CI 14173	W. Q. Loegering	CS	2^{-}
17	W3499	I. A. Watson	W2691	;1
23	CI 12635	English cultivar	Exchange	23C
24	CI 17474	F. G. Gough	LC[d]	$2^{-}2^{+}$
25	CI 17473	USA cultivar	Agrus	2
26	PI 365582	Australian cultivar	Eagle	2
29	PI 193108	French cultivar	Etiole de Choisy	$2^{+}2^{-}$
31		USSR cultivar	Aurora	2^{-};1
McN	CI 15288	USA cultivar	McNair 701	$2^{=}$;
Tmp	CI 13679	USA cultivar	Triumph 64	2^{-}
Tt-1	CI 17385	A. P. Roelfs	W2691SrTt-1 (Line C sel)	0,0;1^{+},40;

[a] Typical low infection type at 65-75° F. It may vary somewhat with environment and culture.

[b] Chinese Spring CI 14108.

[c] Little Club/Gabo*3/Charter.

[d] Little Club.

example, a high IT on the host with an isolate avirulent on Sr7b, 8, 9a, was positive evidence that the three genes were not present in the host. A low IT on the host showed that the host had any one of the three genes or other gene(s) not included in the avirulence/virulence formula. The possible identity of the gene(s) for resistance was tested by the reaction of the host to other isolates with pathogenicity formulae in which avirulence to Sr7b, 8, and 9a, were separated from each other.

Table 3. Low infection type expressed by the interaction of *Puccinia graminis* f. sp. *tritici* and the monogenic lines for wheat stem rust resistance.

Culture	Sr gene																									
	5	6	7b	8	9a	9b	9d	9e	10	11	12	13	14	15	16	17	24	25	26	27	29	31	Tmp	Tt-1	McN	Race
1								$2^{=}$	;1^{-}N			2				0;	;1^{-}	2	$2^{=}$	;	2	$2^{=}$	$2^{=}$			RTQQ
2		;	2	2^{-}	2^{-}	2				;	;1	2^{+}					$2^{=}$	$2^{=}$	;1^{-}	;	$2^{=}$	0;	$2^{=}$	0;	$2^{=}$	SBCS
3		0;		2	2	2^{+}				21		2		XCN		0;	2^{-}	2	$2^{=}$	;	$2^{=}$	$2^{=}$				TDMH
4		0;			$2^{=}$	2^{+}				;1		$2^{=}$		XCN		0;	2^{-}	2^{-}	;1	;	2^{-}	$2^{=}$				TDSH
5		0;		2	2	2						2^{-}		XCN		0;	2	2	;1	;	2^{+}	;1				TLMH
6		;1N		2		23						2^{+}					2	2	$2^{=}$	;	2^{-}	$2^{=}$				TTDT
7		;1^{-}N		2								2^{+}					2	2	$2^{=}$	;	2^{-}	$2^{=}$				TMRT
8		0;			2	23						2		XCN		0;	2	2	;1	;	2^{+}	$2^{=}$				TNMH
9		0;			2	2^{+}						2^{-}		Xn			2	2	;1^{-}	;	2^{-}	$2^{=}$				TNMK
10	;	;$1^{=}$N			$2^{=}$	2		;1	;1N			2				0;	$2^{=}$	2	;	;	2	$2^{=}$	$2^{=}$			HNLQ
11		0;	2	2	2	2	;1	;		;		2			2^{-}		$2^{=}$	$2^{=}$	;1^{-}	;	$2^{=}$	$2^{=}$	$2^{=}$	0	$2^{=}$	LBCN
12		23C	2	2		2	;1	;	1N	;1	;1	2			2^{-}		$2^{=}$	2	;1^{-}	;	2	;1^{-}	$2^{=}$	0;		LCBN
13		21CN	2			2	1	;		;	;1	2			2^{-}		2^{-}	2	;1^{-}	;	$2^{=}$	$2^{=}$	$2^{=}$	0		LFCN
14		0;		2	2^{-}	2BN	2^{-}	;1^{-}		;1	;1	2	23				2	2	;$2^{=}$	;	2^{+}	$2^{=}$		0		MDCT
15		0;		2	2	2^{+}	2^{-}			;1	;1	2	;1^{+}N				$2^{=}$	2	2^{-}	;	2C	$2^{=}$	$2^{=}$	;1		PDCS
16		0;	2			2		;1	;11^{+}N	;1^{-}		2					$2^{=}$	2^{-}	;$1^{=}$	;	23C	$2^{=}$	$2^{=}$	;1		QFBS
17			2		23			;1^{-}				2^{+}					2	2	$2^{=}$	;	2C	$2^{=}$	$2^{=}$	0		QSHS
18				2		2^{+}		;1		;1		2^{+}					2^{-}	2	$2^{=}$	;	2^{+}	1^{-}C	$2^{=}$			RHMS
19				2				;1^{-}		;1		2					2	2	$2^{=}$	;	2^{+}	;1^{-}C	2^{-}			RHKS
20								;1	;1N	;1		$2^{=}$				0;	$2^{=}$	2	$2^{=}$	;	2	$2^{=}$	$2^{=}$			RKCQ
21								$2^{=}$	;1^{-}N	;1^{-}		2					$2^{=}$	2^{+}	$2^{=}$	;	2	$2^{=}$	$2^{=}$			RKCS
22		0;						;1	;1^{+}N			2^{-}				0;	$2^{=}$	2	0;1^{-}	;	2	$2^{=}$	$2^{=}$			RPQQ
23					23			;1				2^{+}					2	2^{+}	$2^{=}$	;	2	$2^{=}$	$2^{=}$	0		RSHS
24	0;	0;	2			2	;1	;1		;1^{-}	;1	2			2^{-}		$2^{=}$	$2^{=}$	;	;	2	0;	$2^{=}$	0		BFCN
25	0		2			2	;1			;1^{-}	;	2					2	2	;1	;	23CN	$2^{=}$	$2^{=}$	0		DKCS
26	0;	0;	2	2	2	2BN		;1^{-}			X	2^{+}			2^{-}		2	2	;	;	2^{+}	$2^{=}$	$2^{=}$	0		GLCN
27	0;	;			2^{-}	2		;1	;1N	1		2				0;	2^{-}	2	;1	;	2	$2^{=}$	$2^{=}$			HDLQ
28	0;				2	2^{+}		;		;1		2^{+}					2^{-}	2	1	;	2	$2^{=}$	$2^{=}$	0		HJCS

Seedlings were grown in vermiculite and fertilized 5 and 8 days after planting with a water-soluble fertilizer (23-19-17 N-P-K) at a rate of 2.5 g per 24 test lines. The 7-day-old seedlings were inoculated with a spore suspension in a light mineral oil carrier, then placed in a dew chamber at 18 C overnight. The next morning the chamber was illuminated (90-110 $\mu E \cdot sec^{1} \cdot m^{2}$) and the temperature rose gradually to 30 C over a 4-hr period so that the dew evaporated slowly. The plants were placed in a greenhouse environment at 18 C supplemented with 100-120 $\mu E \cdot sec^{1} \cdot m^{2}$ of fluorescent light. Fourteen days after inoculation the plants were scored for infection type (8).

Results and Discussion

The genotype postulated for resistance to stem rust of each entry of the International Winter Wheat Performance Nursery 1 through XI is summarized in Table 4. This information will help plant breeders and plant pathologists in planning crosses for incorporating additional genes for resistance to stem rust into future cultivars. It will also indicate potential danger to cultivars if a shift in virulence is found in the stem rust population. Seventeen of the 25 tested genes were postulated as being present. Their frequency among cultivars and countries is shown in Table 5. The four genes occurring with the greatest frequency were: Sr5, 26.5%; SrMcN, 24.3%; Sr17, 20.6%; and Sr8, 15.4%. The other genes, Sr6, 7b, 9a, 9b, 9d, 10, 11, 12, 24, 29, 31, Tmp, and Tt-1 occurred with frequencies of less than 10%. The genes Sr9e, 13, 14, 15, 16, 25, 26, and 27 were not detected in any of the cultivars.

Sr5 and McN had the widest distribution among cultivars and countries. Sr5 is effective against many of the races, that is 14, 17, 21, 24, 116, 212, of stem rust in Europe but is ineffective against the races 11, 15, 32, and 151 of stem rust in the Western Hemisphere. Although SrMcN was widely distributed also, there was no evidence that it was an effective source of stem rust resistance. Sr17 occurred with greater frequency among cultivars than Sr8. Sr8, however, had a wider distribution among countries. Sr31 was present in cultivars from six countries even though it only occurred in 5.9% of the cultivars. SrTt1 was present only in wheats from the U.S.A. and Yugoslavia. Sr9a and 24 were present only in wheats from the Western Hemisphere. The remaining genes for resistance were restricted to few countries.

The frequency of the number of postulated genes for resistance to stem rust within cultivars is shown in Table 6. In 13% of the cultivars, no genes for resistance to stem rust were detected. In 45% of the cultivars only a single gene for resistance was detected comprising 13 of the 17 genes postulated as being present. SrMcN and Sr5 occurred as a single gene, respectively, in 18 and 11 cultivars, Sr31 in seven cultivars, Sr7b in seven cultivars, SrTmp in five cultivars; Sr17 in four, Sr8 in three cultivars, SrTt-1 in two cultivars, and Sr6, 9b, 9d, 11, 24, and 29 were each in a single cultivar.

Table 4. Postulated genes for resistance to *Puccinia graminis* f. sp. *tritici* in cultivars of the International Winter Wheat Performance Nursery I through XI.

Country of origin and cultivar	Permanent treatment code no.	Postulated Sr gene[a]
Argentina		
Bordenave Puan Sag	2501	7b,8,17,+
Australia		
Tars 237	2301	17
Austria		
Adam	1305	5,8,17
NR721/837	1305	5,6,8,10,17
Probstdorfer Extrem	1301	McN
Probstdorfer Karat	1302	5,McN
Samson	1304	17,McN, Seg. 5
Bulgaria		
Burgas 2 (Sort 12-13)	2002	31
Rousalka	2001	7b,8
Sadova 1	2003	8,10
Slavyanka	2004	5,McN,+
Yubiley (2109-36)	2005	8
Canada		
Lethbridge 1327	0102	5
Winalta	0101	Seg. 5,+
Chile		
Budifen (Temu-149-73)	2205	6,9b,10
Carifen 12	2202	McN,+
Galiafen	2204	+
Likafen	2203	6,9d
Lilifen	2201	+, Seg. 11
Czechoslavakia		
Slavia (St-Vur 37)	2601	31
England		
Maris Huntsman	1702	McN
Maris Nimrod	1701	McN
Maris Templar	1703	McN
Federal Republic of Germany		
Absolvent	0307	5
Caribo	0302	McN
Diplomat	0303	10,McN, Seg. 9d
Disponent	0306	31
Heine VII	0301	None
Jubilar	0304	McN
Kormonan	0305	McN
Finland		
Jo 3057	1403	None
Jyva	1401	None
Vakka	1402	None
France		
Cappelle Desprez	0201	McN,+
Talent	0202	5,McN,+

Table 4. cont.

Country of origin and cultivar	Permanent treatment code no.	Postulated Sr gene[a]
Hungary		
Bankuti 1201	0401	7b
Fertodi 293	0402	Tmp
GKF-2	0404	Seg. McN
GKF-8001	0405	5,+
GK Protein	0409	5,McN,+
Martonvasari 2	0403	5
Martonvasari 3 (MV 69/12)	0406	5,+
Martonvasari 4 (MV 26/72)	0407	5,McN
Martonvasari 5	0408	Tmp
Iran		
Rashid	2401	None
Italy		
Demar 4	0505	McN
Flavio	0507	8
Marimp 3	0504	8,McN
San Pastore	0501	8
Sieve	0506	7b,+
Strampelli	0502	8,McN
Victor I	0503	5,6,8
Japan		
Hachimar-Komugi	1503	7b
Hokuei	1501	McN
Kitakomi-Komugi	1502	7b
Mexico		
Inia 66	0601	8,9a,11,+
Lerma Rojo 64	0602	6,9a,+
Super X	0603	9b,11,17
Netherlands		
Clarion	0702	McN
Clement	0705	31
Felix	0701	McN
Lely	0704	Seg. McN
Manella	0703	McN
Romania		
Dacia	1801	McN, Seg. 5&10
Favorit	1803	McN, Seg. 5&10
F26-70	1804	5,8,17
F53-70	1805	None
F54-70	1806	None
F80-73	1809	29
Iulia	1807	5,8
Lovrin 24	1808	31
Moldova	1802	Seg. 5&McN
South Korea		
Yung Kwang	0801	5

Table 4. cont.

Country of origin and cultivar	Permanent treatment code no.	Postulated Sr gene[a]
Sweden		
Odin	0901	None
Starke	0902	None
Switzerland		
Zenith	1901	McN
Turkey		
Bolal	2102	6,+
Kirac 66	2101	6,7b,+
USA		
Colorado		
Lindon	1031	9a,11,17
Indiana		
Arthur	1010	5,8,Tt-1
Benhur	1002	8,10
Oasis	1026	5,8,Tt-1
Purdue 4930A6-28-2-1	1009	7b,9a,10,17
Riley 67	1011	17
Kansas		
Newton (KS-73112)	1034	+
Parker	1008	Tmp
Sage	1027	17,24
Shawnee	1013	9d
Missouri		
Stadler	1014	None
Nebraska		
Centurk	1019	5,6,8,9a,17
CI 13449/Centurk	1035	17,+, Seg. 5
CI 15074(NB68513)	1020	9d,17
Gage	1004	17,24
Lancer	1006	17, Seg. 5&9d
Lancota(NE7011[illegible])	1023	9b,10,17, Seg. 5
Nap Hal/Atlas 66	1033	9b,10
NB67730	1007	9b
NB68719	1029	Seg. 7b
NE7060	1036	5,10,McN
NE73640	1030	10,17, Seg. 6
Scout 66	1012	17
Sentinel	1025	6,8,9a,17
Winter Triticale	1022	Not tested
New York		
Purdue 6922A1-16	1037	Tt-1
Ticonderoga	1032	5,12
Yorkstar	1018	None
North Carolina		
Atlas 66	1001	9b,10
Blueboy	1003	None
Blueboy II	1024	24
Oklahoma		
Triumph 64	1017	Tmp

Table 4. cont.

Country of origin and cultivar	Permanent treatment code no.	Postulated Sr gene[a/]
Texas		
Sturdy	1015	9d,McN
TAM 102	1021	7b,+
Washington		
Gaines	1005	None
Wa5829	1028	None
Wisconsin		
Timwin	1016	5,17,Tt-1
USSR		
Aurora	1203	5,31
Bezostaya 1	1201	5,+
Karlik 1(Dwarf Bezostaya)	1202	5
Kavkaz	1204	5,31
Krasnodarskaya 39	1207	Seg. 5
Mironovskaya 808	1208	Tmp
Odessa 4	1209	31
Odesskaya 51	1205	+
Priboy	1206	None
Yugoslavia		
Backa	1601	McN
Biserka	1607	5
Dunav-1	1601	9b,17
NSR-1	1613	17,Tmp
NS 732	1603	McN
Partizanka	1612	5,McN
Sava (NS611)	1602	17
Zg 887/73	1608	Tt-1
Zg 4240/73	1609	8,Tt-1
Zg 4293/73	1610	5,11,17,Tt-1
Zg 4364/73	1611	17,Tt-1
Zg 5996/66 (Sanja)	1605	17,8,+
Zlatna dolina (Golden Valley;Zg 5994/66)	1604	17, Seg. 8

a/ + = unidentified gene or genes.

Table 5. Frequency of genes for resistance to stem rust found among cultivars and countries of the International Winter Wheat Performance Nursery I through XI.

Sr gene	% Occurrence among cultivars	% Occurrence among countries
5	26.5	48
6	6.6	24
7b	7.4	28
8	15.4	32
9a	2.9	8
9b	5.1	16
9d	4.4	12
10	9.6	24

Table 5. cont.

Sr gene	% Occurrence among cultivars	% Occurrence among countries
11	3.7	16
12	0.7	4
17	20.6	24
24	2.2	4
29	0.7	4
31	5.9	24
McN	24.3	60
Tmp	4.4	16
Tt-1	5.9	8

Table 6. Frequency of the number of genes for stem rust resistance per cultivar in the International Winter Wheat Performance Nursery I through XI.

No. of genes per cultivar	Percent
0	13.2
1	45.6
2	23.5
3	14.7
4	1.5
5	1.5

Two genes for resistance were detected in 23% of the cultivars in 19 combinations. The combination Sr5, McN occurred seven times. All other combinations occurred one or two times. Sr8 and and 17 were involved in six combinations, Sr5 was involved in five combinations, and Sr6 was involved in three combinations.

Three genes for resistance were detected in 12% of the cultivars in 16 combinations. The combination Sr5, 10, and McN occurred three times, Sr5, 8, and Tt-1 each occurred twice, and all other combinations occurred once. Four and five genes for resistance were detected in each of two cultivars, each a different combination. Sr17 and 10 were present in each of the combinations.

No resistance genes were detected in cultivars from Finland, Iran, and Sweden. Most cultivars were protected by only one or two genes. It is possible that the genes Sr9d and Sr12 may be present in more cultivars but were not detected because of the presence of other genes which condition the same of lower infection type. Sr16 may be present but was undetected for the same reason. The stem rust isolates detected unidentified genes in some of the cultivars. Galifen 12 was resistant to all 28 isolates; however the gene(s) were undetermined. The IT varied from ;1c to 23 and did not fit the pattern of any of the 25 tested genes. Bezostaya 1, GFK Protein, Martonvasari 3, and Slavyanka appear to have an unidentified

gene in common because they were resistant to avirulent isolate LCBN. Carifen 12 and Odesskaya 51 also appear to have an unidentified gene in common because they were resistant to avirulent isolate BFCN.

References

1. Flor, H. H. 1971. Current status of the gene-for-gene concept. Annu. Rev. Phytopathol. 9:275-296.
2. Loegering, W. Q., R. A. McIntosh, and Coleman H. Burton. 1971. Computer analysis of disease data to derive hypothetical genotypes for reaction of host varieties to pathogens. Can. J. Genet. Cytol. 13:742-748.
3. McIntosh, R. A. 1973. A catalogue of gene symbols for wheat. Int. Wheat Genet. Symp., Proc. 4th Mo. Agr. Exp. Stn., U. of Mo., Columbia (Aug. 5-12, 1973).
4. McVey, D. V., and A. P. Roelfs. 1975. Postulation of genes for stem rust resistance in the entries of the Fourth International Wheat Performance Nursery. Crop Sci. 15:335-337.
5. Oort, A. J. P. 1963. A gene-for-gene relationship in the Triticum-Ustilago system and some remarks on the host-parasite combinations in general. Neth. J. Plant Pathol. 69:104-109.
6. Rajaram, S. 1970. Genetic analysis of rust resistance in common wheat. Indian J. Genet. Plant Breed. 30:291-297.
7. Roelfs, A. P., and D. V. McVey. 1979. Low infection types produced by Puccinia graminis f. sp. tritici and wheat lines with designated genes for resistance. Phytopathology 69:722-730.
8. Stakman, E. C., D. M. Stewart, and W. Q. Loegering. 1962. Identification of physiologic races of Puccinia graminis var. tritici. U. S. Dept. Agric. ARS E-617 (revised). 53 pp.
9. Stroike, J. E., V. A. Johnson, J. W. Schmidt, and P. J. Mattern. 1971. Results of the First International Winter Wheat Performance Nursery. Nebr. Agr. Exp. Stn. Res. Bull. 245.

REACTION OF DIFFERENT SOURCES OF RESISTANCE IN WHEAT TO THE PREVALENT RACES OF THE CEREAL RUST IN TURKEY 1973-1979

Necati Celik
Turkey

Leaf Rust (Puccinia recondita Rob. ex Desm. f. sp. tritici), stem rust (P. graminis f. sp. tritici) and Stripe Rust (striiformis) are very common in wheat fields of Turkey were all the older varieties extensively cultivated are very susceptible. The pathogen race population has been shown to be different and variable through the years and regions. During the previous eight years more than fifteen races have been isolated from samples collected on "durum" and "bread" wheat. Races UN.17, 13, 19, 12 and 15 for leaf rust; 70E0, 70E16, 6E0, 6E2, 6E16, 2E6 and 22E0 for stripe rust and RKR, TKR, RTR, TKH, TKQ, HKR for stem rust have been identified.

In general, the virulence factors present in the leaf and stripe rust populations are similar to those present in other European and Balkan countries. Cariello et al.,1976 (5) found leaf rust races 77 and 57 to be the most common. Donchev (6) has used race 77 for his material testing in Bulgaria. Salazar, Branas, and Martinez (13) also found UN 13 (77) race to be the most common in Spain. Boskovic (4) initially found only UN races 3 and 13 while later only UN race 13 was identified in 80-90 per cent of total isolates identified. These results also are similar to our results.

If we compare the Turkish stripe rust situation to other neighboring countries we also find similarities. Negulesco, et al.,(8) reported races 2E0, 6E0, 6EZ, and E16 to be the most common from 1964 to 1974. This is similar to our results here in Turkey.

Puccinia striiformis.--The new race nomenclature given in Table 1 was proposed by Johnson et al.,(1972) and is based on a binary notation (Hapgood 1970). The percentages of virulent effect are also given in Table 1.

Heines Kolben and Lee were susceptible to all collections and the varieties containing Yr Sw92 and Yr 8 were also susceptible to most of the collections. Over the last nine years only the differential varieties Chinese 166 (Yr1) and NordDespres have remained resistant. The differential varieties Heines VII, T. Spelta Alba, Hybrid 46, and Strubes Dickkop are also still useful. Our results indicate the most common races of stripe rust in Turkey are 86E16, 70E16 and 70E0.

Puccinia recondita f. Sp tritici.--The race nomenclature of UN (Unified Numeration) races proposed by Johnston (11) and Basile (2) and the total percentage of virulent effect are given in Table 2. In this study we used five differential and four supplemental

Wheat Research and Training Center -- Turkey, Ankara.

Table 1. Physiologic race survey of *Puccinia striiformis* f. sp. *tritici*. The presence of virulence factors in Turkey (73-79).

Differential varieties	Genotype	73-74	74-75	75-76	76-77	77-78	78-79	Virulent effect total percentage
Suwon92-Omar	Yr SW92	X		X	X	X	X	88
Strubes Dickkopf			X					4
Moro	Yr PI 178383			X	X	X	X	38
Vilmorin 23	Yr 3a		X	X				6
Heines Kolben	Yr 6	X	X	X	X	X	X	100
Lee	Yr 7	X	X	X	X	X	X	100
Chinese 166	Yr 1							0
Heine VII	Yr 2		X					2
Spaldings Prolific	Yr 5							0
Carstens V								0
Compair	Yr 8	X	X	X	X	X	X	86
Nord Desprez								0
T. spelta alba	Yr 6		X					3
Reichersberg			X	X				11
Hybrid 49	Yr 46		X					4
Prevalent races		2E16 70E16 6E16	14E134 46E134 46E151	70E0 70E16 22E0 6E0 6E2	70E0 86E16 70E16	86E16 6E0	86E16 70E16 6E0	

Table 2. Physiologic race survey of *Puccinia recondita* f. sp. *tritici*. The presence of virulence factors in Turkey (73-79).

Differential varieties	Genotype	73-74	74-75	75-76	76-77	77-78	78-79	Virulent effect total percentage
Malakof	Lr 1		X	X	X	X	X	33
Webster	Lr 20	X	X	X	X	X	X	98
Loros	Lr 2d	X	X	X	X	X	X	90
Mediterranean	Lr 3	X	X	X	X	X	X	97
Democrat	Lr 3	X	X	X	X	X	X	85
Agent	Lr 23	X	X				X	3
Agrus	Lr 19							0
Waban	Lr 4	X	X	X	X	X	X	15
Transfer	Lr 9	X	X	X	X	X	X	10
Prevalent races		UN 17 UN 19 UN 12 UN 4	UN 17 UN 13	UN 17 UN 13 UN 19	UN 17 UN 13	UN 17 UN 13 UN 15	UN 17 UN 13 UN 12 UN 22	

single gene varieties. If we compare the five differential varieties with each other only Malakof (LR 1) is really effective. Boskovic has also tested collections from Turkey. He found 43% UN 13 and 10.8 % UN 17 races in the samples. On the other hand, the supplemental differentials had better resistance than the differentials. The variety, Agrus (LR 19), has remained effective for the last nine years. Also Agent (LR-23) is also an effective resistance gene.

Puccinia graminis f. sp Tritici.--The race nomenclature and percentage of virulent effect are given in Table 3. In this study we used twelve differential varieties. Only Sr13 has remained effective. Also Sr-11 and Sr-dlv were somewhat effective. We used USDA Cereal Rust Laboratory (CRL) codes for cultures of graminis f. sp tritici characterized on differentials each with a single gene for resistance.

Roelfs, et al., (12) also has reported Sr 13 to be effective and unbroken to all the collections in their rust virulence survey.

Reaction of different sources of resistance.--Over the last six years we have tested many lines or varieties in both seedling and field experiments. Table 4 presents the results of these experiments. Sut^5-Ag and L320-H21 lines have a high level of resistance to all biotypes of the three rusts. In addition to these two lines, Kavkaz Sel 7 and Skorospelka 35 also had good resistance to all the prevalent biotypes of stem and yellow rust under greenhouse conditions. Donchev, et al., (7) also found Skorospelka 35 to be a good source of resistance for leaf rust UN17 and UN13 races. These results are similar to our findings in Turkey. However, Skorospelka 35 was susceptible to UN19. On the other hand, Bartos (1) found Kavkaz resittance effective for UN13. We also tested both Kavkaz Sel 7 and Sel 4 and found they were effective against UN13 and UN17 leaf rust races in Turkey but susceptible to UN19. These different varieties or lines also have given resistant reactions under field conditions.

Finally, we are using these lines or varieties in our breeding program for developing new resistant varieties.

References

1. Bartos P. 1973. Genetics of stem and leaf rust resistance of the Wheat Cultivar Kavkaz. Vedecke Prace Vyzkumnych Rostlinne VYroby, Praha, Ruzyne-19.
2. Basile, R. 1957. A diagnostic key for the identification of physiologic races of Puccinia rubigo- vera tritici grouped according to a unified numeration scheme. U. S. D. A., PDR 41: 508-511.
3. Boskovic. 1972. European and Mediterranean wheat leaf rust procet. Proceedings of the European and Mediterranean Cereal Rust Conference, 35-50 p.
4. Boxkovic, M. M. 1976. International Pathopenicity Survey of Puccinia recondita F. Sp. tritici. Fourth European and Mediterranean Cereal Rust Conference Proceeding, 75-78 p.
5. Cariello, G. P., Trantini, Casulli, and Vallega 1976. Effi-

Table 3. Physiologic race survey of *Puccinia graminis* f. sp. *tritici*. The presence of virulence factors in Turkey (73-79).

Differential varieties	73-74	74-75	75-76	76-77	77-78	78-79	Virulent effect total percentage
Sr 5	V	V	V	V	V	V	100
Sr ad	V	V	V	V	V	V	88
dlv ge	R	R	R	R	R	V	5
Sr 76	V	V	V	V	V	V	76
Sr 11	R	R	V	V	R	V	4
Sr 6	V	V	V	V	V	V	84
Sr 8	V	V	V	V	V	V	92
Sr 9a	V	V	V	V	V	V	76
Sr 14	V	V	V	V	V	V	76
Sr 16	R	V	V	V	V	V	80
Sr 13	R	R	R	R	R	R	0
Sr 10	V	V	V	V	V	V	68
Prevalent races	RKR GBB GBB GFR GCR	HKR MHM CHR HDH QJM	RKR RLR CTB CQM	RKR RJM QPH RTR MRR	RKR GBB GFR HMM	RKR SKR TKR TKH TKQ QKG RKM	

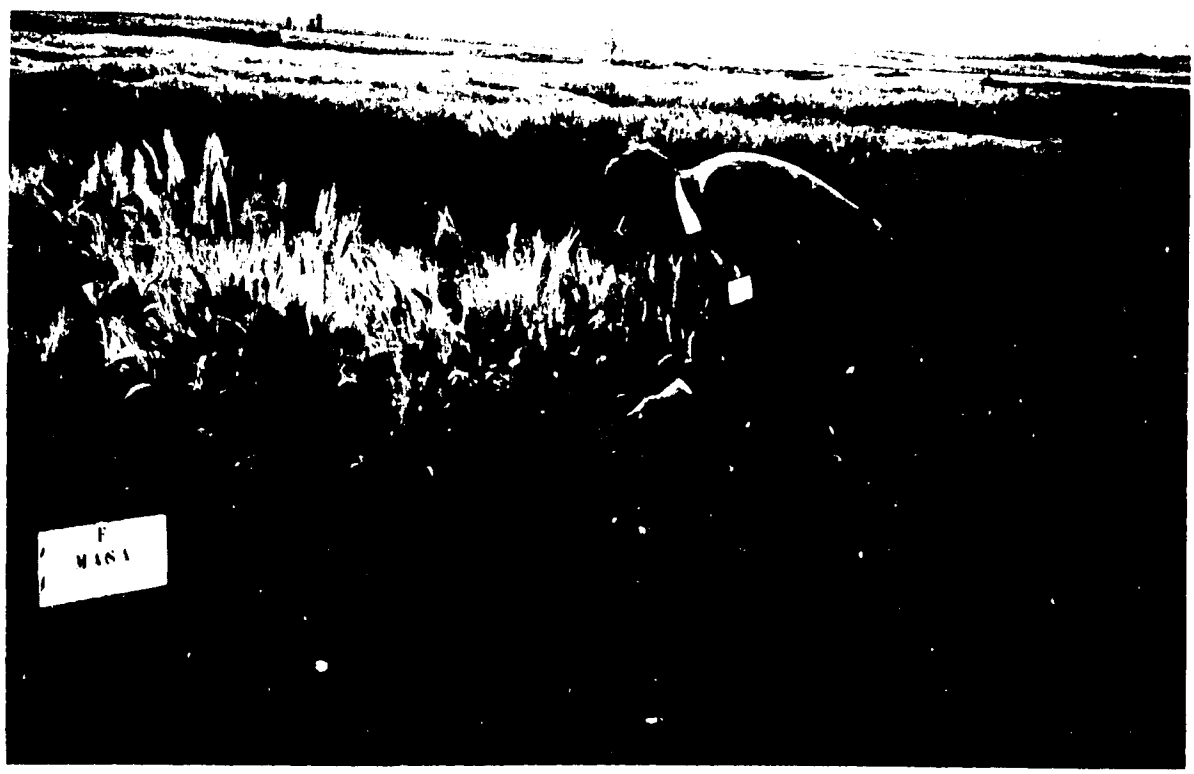
Table 4. Greenhouse and field reaction of several sources of resistance to three prevalent races of rusts.

Source of resistance	Greenhouse reaction(1)									Field reaction(2)		
	Yellow rust			Stem rust			Leaf rust			LR	SR	YR
	86E16	70E16	70E0	RKR	CHR	RLR	UN 17	UN 13	UN 19			
Kavkaz sel. 7	R	R	R	R	R	R	R	R	S	10MR	0	10MR
Kavkaz sel. 4	R	R	R	R	R	R	R	R	S	0	0	5MR
Aurora	R	R	R	R	S	R	R	R	R	0	10MS	0
Skorospelka 35	R	R	R	R	R	R	R	R	S	0	10S	10MS
Lovrim 10	R	R	S	R	R	R	R	R	R	0	0	10MS
L 320 - H21	R	R	R	R	R	R	R	R	R	0	0	0
Dobrisch 1	R	R	S	R	S	R	R	R	R	10MR	10S	10MS
Penjamo 62 - Albudin 43	R	R	R	R	R	S	R	R	R	10MR	20S	10S
Haymana 79 = Sut^5 - Ag	R	R	R	R	R	R	R	R	R	0	0	0

(1) The reaction is expressed by type of infection in seedling stage in the greenhouse.
(2) Artificially infected plot. Severity and response are reported.

ciency of Certain Resistance genes and reaction of some wheat varieties to "Leaf Rust" in Italy. Fourth European and Mediterranean Cereal Rust Conference Proceeding. 117-119 p.

6. Donchev,N. 1976. Results from the selection work on Developing Rust Resistant Common Wheat Varieties in Bulgaria. Fourth European and Mediterranean Cereal Rust Conference Proceeding. 120-125 p.
7. Donchev, N., L. Doncheava, K. Mallinsky. 1972. Similarity and difference in genes of resistance with some winter varieties of soft wheat to leaf rust. Proceeding of European and Mediterranean Cereal Rust Conference 81-85 p.
8. Egulescu, F. and M. Lonescu-cojocaru. 1976. Aspects of Puccinia striformis F. Sp tritici Physiologic Specialization in Romania. Fourth European and Mediterranean Cereal Rust Conference Proceeding. 81-84 p.
9. Hapgood, R. M. 1970. Nature 227, 1268.
10. Johnson, R., R. W. Stubbs, E. Fuchs, and N. H. Chamberlain. 1972 Trans. Br. Mycol. Soc. 58 (13) (in print).
11. Johnston , C. D. 1965. Unified number for races of Puccinia triticina, Ribigo 1.2.
12. Roelfs, A. P., D. H. Casper, and D. L. Long. 1978. Races of Puccinia graminist f. Sp. tritici in the USA during 1977. PDR 62: 735-739.
13. Salazar, J., M. Branas and M. Martinez. 1976. Physiological Specialization Df Wheat Leaf Rust in Spain. 1972-1973. Fourth European and Mediterranean Cereal Rust Conference Proceeding. 90-91 p.



GENETIC ANALYSIS OF SLOW LEAF-RUSTING RESISTANCE IN WHEAT

R. N. Kulkarni and V. L. Chopra
India

Abstract

Latent period, initial uredium area, rate of increase in uredium area and spores produced per uredium per day by *Puccinia recondita* f. sp. *tritici*, on three slow-rusting (HD 2009, Sonalika and L 1435/4581 x 8156) and two fast-rusting (Kharchia Local and Lal Bahadur) genotypes of wheat were compared, both at seedling and adult plant stages. While no differences could be detected between fast- and slow-rusters for any of the components at seedling stage, significant differences could be detected at adult plant stage. The fast-rusters had a shorter latent period, produced larger uredia and more spores per uredium per day than slow-rusters. However, fast- and slow-rusters produced similar number of spores per unit uredium area per day. Correlation analyses indicated that spores produced per uredium per day and rate of increase in uredium area were important components and that together they accounted for 74 per cent of variation in slow-rusting resistance in the field (measured in terms of area under disease progress curve). Latent period and initial uredium area had negligible direct effects. The various components were themselves highly intercorrelated.

A 5 x 5, F_1-diallel analysis carried out to study the genetics of slow-rusting resistance and its components indicated that all the components and slow-rusting resistance (measured in terms of area under disease progress curve) were predominately under the control of additive gene action. All the components, except spores produced per uredium per day, had lower estimates of heritability than area under disease progress curve.

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During the past few years several studies have elucidated the various mechanisms that ultimately produce slow rusting resistance. Longer latent period, reduced infectibility, reduced pustule size, reduced sporulation rate and shorter infectious period have been found to be the primary components of slow rusting resistance (Heagle and Moore, 1970; Ohm and Shaner, 1976; Johnson and Wilcoxson, 1978; Kuhn *et al.*, 1978; Neervoort and Parlevliet, 1978; Shaner *et al.*, 1978). The inheritance of slow rusting resistance or of its components has been studied only recently (Ohm and Shaner, 1975; Parlevliet, 1976; Knott, 1977; Parlevliet, 1978; Gavinlertvatana and Wilcoxson, 1978; Skovmand *et al.*, 1978; Johnson and Wilcoxson, 1979). This paper deals with the components and genetic analysis of slow leaf rusting resistance in wheat (*Triticum aestivum* L.).

Indian Agricultural Research Institute, New Delhi.

Material and Methods

The host genotypes consisted of two fast-rusters (Kharchia Local and Lal Bahadur) and three slow-rusters (Sonalika, HD 2009 and L 1435/4581 x 8156). A single race, 77A, of Puccinia recondita f. sp. tritici, which was fully virulent on all the above genotypes, was used.

The ability of the wheat genotypes to retard leaf rust development in the field was evaluated in two experiments during 1977-78 and in one experiment during 1978-79. A completely randomized design was used and consisted of three replications made up of two row plots that were two meters long. One spreader row was sown on either side of each plot. The spreader rows were inoculated with race 77A of P. recondita about one month after sowing. Leaf rust severities were estimated, using modified Cobb's scale (Peterson et al., 1948), at an interval of 14 days during 1977-78 and at an interval of 10 days during 1978-79. Apparent infection rate and area under disease progress (AUDPC) were calculated using the formula given by Vanderplank (1968) and Shaner and Finney (1977), respectively.

Four components of slow rusting resistance viz., latent period, initial uredium area, rate of increase in uredium area and spores produced per uredium per day by P. recondita on the five genotypes of wheat were estimated in replicated experiments at seedling and flag leaf stages. Inoculations were done by spraying a suspension of uredospores (2 mg per ml) in one percent Tween-20 as uniformly as possible. Latent period was estimated according to Shaner et al., (1978). Uredia were measured under the microscope when all the uredia had emerged and again six days later (when generally the secondary uredia became visible). Uredium area was calculated using the formula of Katsuya and Green (1967). Rate of increase in uredium area was calculated from the two measurements on uredium area. Spores were collected and their number determined using a haemocytometer.

For genetic analysis, the five wheat genotypes and their 10 hybrids obtained by crossing in all possible combinations (without reciprocals) were studied for their components of slow rusting resistance and for their ability to retard leaf rust development in the field in terms of apparent infection rate and AUDPC, in experiments similar to those on the parents described earlier. The components of genetic variation were calculated according to Hayman (1954) and narrow sense heritability was calculated according to Crumpacker and Allard (1962). The data were also subjected to multiple regression and path coefficient analyses (Dewey and Lu, 1959).

Results and Discussion

The differences among wheat genotypes for their abilities to retard leaf rust development in the field were significant in all the three experiments (Table 1). Lal Bahadur and HD 2009

were consistently fast- and slow-rusters, respectively, in all the three experiments. However, it can be seen from Table 1 that the differences in apparent infection rates between fast- and slow-rusters were not consistent from experiment to experiment. On the other hand, AUDPC consistently distinguished the fast- and slow-rusters. The differences in AUDPC between fast- and slow-rusters were also large. Wilcoxson et al., (1975) found that differences in AUDPC were consistent from trial to trial and reflected observations on rust development in plots. The data of Ohm and Shaner (1976) also

Table 1. Area under leaf rust progress curve (AUDPC) and rate of leaf rust increase for different genotypes of wheat.

Genotypes	1977-78				1978-79	
	Apparent infection rate		AUDPC		Apparent infection rate	AUDPC
	Expt. I	Expt. II	Expt. I	Expt. II		
Kharchia Local	0.321a	0.157a	1990a	2378a	0.221a	1158a
Lal Bahadur	0.349a	0.187b	2035a	2543a	0.256a	1243a
HD 2009	0.122b	0.123c	447b	664b	0.152b	230b
Sonalika	0.141b	0.151a	592b	546b	0.246a	251b
L1435/ 4581x8156	0.150b	0.164a	176c	185c	0.166b	171b

Means followed by the same letters within an experiment do not differ at 5 per cent level of significance.

indicate that apparent infection rate cannot distinguish fast- and slow-rusters when estimates are based on experiments with small plots. Berger (1975) reported that apparent infection rates were associated with considerable variation during the course of the epidemic. Apart from the errors introduced by lack of linearity in $\log_e [Y/(1-y)]$ plotted against time, the value of apparent infection rate is strongly affected by minor differences in disease severities early in the season when disease severities are low (Shaner and Finney, 1977). The apparent infection rate is useful in analysing epidemics and predicting the effects of various disease control measures but it has serious drawbacks as a statistic for quantifying slow rusting resistance in small plots (Shaner and Finney, 1977; Fry, 1978).

Slow rusting resistance in terms of its components could not be detected at seedling stage as there were no significant differences among the wheat genotypes for any of the components studied (Table 2). Mashaal et al., (1977), also working with leaf rust of wheat, could not detect slow rusting resistance in seedling plants. Parlevliet (1975), working with barley leaf rust, found that differences among cultivars for latent period were relatively too small to be detected and in many cases did not predict latent period on adult plants. However, several other workers have reported varietal differences for various components in other host-parasite relationships (Heagle and Moore, 1970; Wilcoxson et al., 1974: Sztejnberg and Wahl, 1976; Wahl et al., 1980). The differences among the genotypes for various components in adult plants were relatively larger than in seedlings and were statistically significant (Table 3). The slow-rusters had a longer latent period,

Table 2. Estimates of different components* of slow rusting resistance in different genotypes of wheat at seedling stage.

Genotypes	Latent period (days)		Initial uredium area (mm^2)		Spores/uredium/day	
	Expt. I	Expt. II	Expt. I	Expt. II	Expt. I	Expt. II
Kharchia Local	8.6	9.1	0.158	0.149	1909	2055
Lal Bahadur	8.7	9.4	0.139	0.148	2301	1860
HD 2009	8.6	9.6	0.121	0.143	1778	1879
Sonalika	9.5	10.3	0.112	0.125	1489	1366
L1435/4581x8156	9.5	10.0	0.139	0.132	1660	1548

* Rate of increase in uredium area was not calculated because genotypic differences for uredium area estimated at two different intervals were not significant.

Table 3. Estimates of different components of slow rusting resistance in different genotypes of wheat at adult plant stage.

Genotypes	Latent period		Initial uredium area (mm^2)		Rate of increase in uredium area mm^2/day		Spores/uredium/day*	Spores/mm^2 of uredium/day*
	Expt. I	II	Expt. I	II	Expt. I	II	Expt. II	Expt. II
Kharchia Local	9.5 a	9.6 a	0.168 a	0.173 a	0.040 a	0.018 a	1697 a	7009 a
Lal Bahadur	10.9 ab	10.6 a	0.110 b	0.107 b	0.013 bc	0.014 ab	1325 b	8240 a
HD 2009	11.2 b	11.1 a	0.102 bc	0.109 b	0.008 bc	0.008 b	1117 bc	7905 a
Sonalika	13.3 c	12.9 b	0.093 c	0.083 bc	0.007 bc	0.007 b	1000 c	8946 a
L1435/4581x8156	13.7 c	13.1 b	0.071 d	0.076 c	0.005 c	0.007 b	908 c	8770 a

* Sporulation was estimated in Experiment II only. Means followed by the same letter within an experiment do not differ at 5 per cent level of significance.

produced less spores per uredium per day and had smaller uredia that increased in size more slowly than those on fast-rusters. The slow-rusters produced a lesser number of spores per uredium per day than fast-rusters mainly because they had smaller uredia. This was apparent when sporulation was expressed as number of spores per unit area of the uredium. However, some of the components of the slow-rusters did not differ significantly from those on the fast-ruster Lal Bahadur. None of the components of slow-ruster HD 2009 were significantly different from those of fast-ruster Lal Bahadur although HD 2009 had slightly longer latent period and had uredia that increased more slowly and produced lesser number of spores than Lal Bahadur. These small differences might have been magnified many times over several infection cycles in the field resulting in smaller apparent infection rate and AUDPC values for HD 2009 than for Lal Bahadur. In general, the various components reflected the differences in the ability of different cultivars to retard rust development in the field fairly well.

Only two components, namely, rate of increase in uredium area and spores produced per uredium per day were significantly correlated with apparent infection rate (Table 4). The magnitude of these correlations was small. In contrast, AUDPC was highly significantly correlated with all the four components studied. This may be a reflection of the fact, discussed earlier, that AUDPC is a better measure for quantifying slow-rusting resistance in small plots than apparent infection rate. All the components themselves were highly intercorrelated. This is theoretically expected (Parlevliet and van Ommeren, 1975; Ohm and Shaner, 1976; Johnson and Wilcoxson, 1978; Neervoort and Parlevliet, 1978; Vanderplank, 1978). However, the components were not completely associated since latent period on Lal Bahadur was equal to that on Kharchia Local but uredia of Lal Bahadur were slightly larger than half the size of uredia on Kharchia Local. Therefore, it should be possible to combine different components to increase the level of resistance.

Partitioning of the correlations into direct and indirect effects revealed that latent period and initial uredium area had negligible direct as well as indirect effects. Sporulation and rate of increase in uredium area had large direct as well as indirect effects (Table 5). The importance of these two components was also evident from the multiple regression analysis (Table 6). Together, they accounted for 74 per cent of variance for AUDPC in the field. Approximately 26 per cent of the variance for AUDPC in field was not accounted for by the four components studied. Factors like infectibility, infectious period, crop morphology, differences in plant maturity and differences in glasshouse and field environments might have contributed to this unaccounted variance (Ohm and Shaner, 1976; Neervoort and Parlevliet, 1978).

The estimates of genetic components of variation were estimated following the procedure of Hayman (1954). An additive-dominance model with independent gene distribution was found to be adequate for explaining the genetic variation in AUDPC, latent period, uredium area and sporulation. Since the regression

Table 4. Intercorrelations between AUDPC, infection rate and components of slow-rusting resistance.

	AUDPC	Infection rate	Latent period	Initial uredium area	Rate of increase in uredium area	Sporulation
AUDPC	1.0000	0.6211**	-0.7552**	0.7164**	0.6520**	0.8286**
Infection rate		1.0000	0.2540	0.2858	0.3592*	0.3033*
Latent period			1.0000	-0.7172**	-0.7021**	-0.8097**
Initial uredium area				1.0000	0.5699**	0.8084**
Rate of increase in uredium area					1.0000	0.5635**

Table 5. Analysis of phenotypic correlation into direct and indirect effects.

Character	Correlation with AUDPC	Indirect effects via			
		Latent period	Initial uredium area	Rate of increase in uredium area	Sporulation
Latent period	-0.7552	-0.0650	-0.0311	-0.1688	-0.4902
Initial uredium area	0.7165	0.0467	0.0433	0.1371	0.4894
Rate of increase in uredium area	0.6520	0.0457	0.0247	0.2404	0.3412
Sporulation	0.8286	0.0527	0.0350	0.1355	0.6054

Underlined values are direct effects (path coefficients).

Table 6. Coefficient of determination of various multiple regression equations between AUDPC and components of slow-rusting resistance.

Character combination	H^2	B-coefficients 1. Latent period	2. Initial uredium area	3. Rate of increase in uredium area	4. Sporulation	
1	0.5703	-195.3*				2877.8*
2	0.5134		8029.7			-324.6
3	0.4253			26030.5*		185.2
4	0.6866				0.6942*	-628.3
1,2	0.6333	-128.5*	4034.8*			1651.5
1,3	0.5996	-151.7*		9589.4		2231.7
1,4	0.7072	-63.3			0.5282*	412.3
2,3	0.6014		5723.8*	14410.3*		-260.2
2,4	0.6929		1506.8		0.6031*	-634.6
3,4	0.7368			10826.5*	0.5661*	-549.4
1,2,3	0.6525	-97.8*	3733.9*	7850.6		1214.0
1,2,4	0.7101	-58.9	1045.6		0.4765*	335.8
2,3,4	0.7375		533.4	10508.3*	0.5376	-554.0
1,2,3,4	0.7386	-16.81	485.7	9601.8*	0.5071	-283.9

coefficient (b Wr/Vr) was significantly different from unity for the characters apparent infection rate and rate of increase in uredium area, a four parent sub-diallel was analysed by eliminating the parent Sonalika. The estimates of various genetic components of variation and narrow sense heritability estimates for different characters are given in Table 7. All the characters, except apparent infection rate, were predominantly governed by additive gene action. For apparent infection rate, both additive and non-additive types of gene action were equally important. Slow rusting resistance to leaf rust in wheat has recently been reported to be controlled by 3 to 21 gene pairs with a narrow sense heritability of 55 to 87 per cent (Gavinlertvatana and Wilcoxson, 1978). Skovmand et al., (1978) found that slow rusting resistance to stem rust in wheat was highly heritable (heritability 80 per cent) and was controlled by 2 to 12 gene pairs. The heritability estimates of slow rusting to leaf rust in different crosses of barley cultivars ranged from 53 to 89 per cent (Johnson and Wilcoxson, 1979). The narrow sense heritability of slow rusting resistance measured in terms of AUDPC in the present study was high and is in agreement with the estimates obtained by other workers mentioned earlier. Low heritability of apparent infection rate in comparison to that of AUDPC again indicated its disadvantage as a measure of slow rusting resistances in breeding programmes. Heritability estimates of slow rusting resistance measured variously in self fertilizing cereals have ranged from 46 to 92 per cent (Luke et al., 1975; Simons, 1975; Krupinsky and Sharp, 1978).

Among the components, sporulation had the highest heritability followed by uredium area, latent period and rate of increase in uredium area. Ohm and Shaner (1975) found that latent period, pustule size and pustule density of P. recondita on wheat were controlled by factors with additive effects. The narrow sense heritability estimates of latent period of barley leaf rust fungus ranged from 54 to 59 per cent in fast- x fast-ruster and slow- x slow-ruster crosses, respectively (Johnson and Wilcoxson, 1979). Brennan (1975) found that size and number of uredia of stem rust of wheat were controlled by additive and epistatic gene action. The inheritance of sporulation and rate of increase in uredium area has not been studied earlier. The heribability estimate of latent period was of similar magnitude as that obtained for barley leaf rust by Johnson and Wilcoxson (1979); the only report on heritability of latent period.

Thus, from the correlations and genetic analyses it appears that indirect selection for slow rusting resistance through any of the four components studied would not be advantageous. This is because the components indicated by correlation analysis as important, viz., sporulation and rate of increase in uredium area, are laborious and time consuming to estimate. Also, since slow-rusting resistance, measured directly in terms of AUDPC, is predominantly governed by additive gene action with a high narrow sense heritability it should be possible to make rapid progress through direct selection for AUDPC.

Table 7. Estimates of genetic components of variation and narrow sense heritability for slow-rusting resistance and its components.

Parameter	Apparent infection	AUDPC ($x10^{-2}$)	Latent period	Initial uredium area ($x10^2x$)	Rate of increase in uredium area ($x10^2x$)	Spores/ uredium/ day($x10^{-2}x$)
D	21.48**	29.09**	2.97**	22.11**	0.82**	38.74**
H_1	28.70**	11.77**	0.68	6.11	0.06	0.59
H_2	27.17**	8.72	0.62	5.29	0.08	0.83
F	2.88	0.48	-1.09**	0.04	-0.76*	-7.36*
E	1.88	0.11	0.07	0.06	0.20**	0.99**
Heritability (Narrow Sense)	40.16	71.34	59.03	72.57	33.77	76.47

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References

Berger, R. D. 1975. Rapid disease progress in early epidemic stages. Proc. Am. Phytopathol. Soc. 2:35 (Abstr.).

Brennan, P. S. 1975. General resistance in wheat (Triticum aestivum L.) to stem rust (Puccinia graminis tritici Pers. f. sp. tritici Erikks and Henn.). Ph.D. Thesis, Univ. Saskatchewan, Saskatoon, 142 pp. - as quoted by Skovmand et al., (1978).

Crumpacker, D. W. and R. W. Allard. 1962. A diallel analysis of heading date in wheat. Hilgardia 32:275-318.

Dewey, D. R. and K. H. Lu. 1959. A correlation and path coefficient analysis of components of crested wheat grass seed production. Agron. J. 51:515-518.

Fry, W. E. 1978. Quantification of general resistance of potato cultivars and fungicide effects for integrated control of potato late blight. Phytopathology 68:1650-1655.

Gavinlertvatana, S. and R. D. Wilcoxson. 1978. Inheritance of slow rusting of spring wheat by Puccinia recondita f. sp. tritici and host parasite relationships. Trans. Br. Mycol. Soc., 71:413-418.

Hayman, B. I. 1954. The theory and analysis of diallel crosses. Genetics 39:789-809.

Heagle, A. S. and M. B. Moore. 1970. Some effects of moderate adult resistance to crown rust in oats. Phytopathology 60:461-466.

Johnson, D. A. and R. D. Wilcoxson. 1978. Components of slow-rusting in barley infected with Puccinia hordei. Phytopathology 68:1470-1474.

Johnson, D. A. and R. D. Wilcoxson. 1979. Inheritance of slow-rusting of barley infected with Puccinia hordei and selection for latent period and number of uredia. Phytopathology 69:145-151.

Katsuya, D. and G. J. Green. 1967. Reproductive potentials of races 15B and 56 of wheat stem rust. Can. J. Bot., 45:1077-1091.

Knott, D. R. 1977. Studies on general resistance to stem rust in wheat. In: "Induced Mutations against Plant Diseases", IAEA, Vienna, Austria. p.81-88.

Krupinsky, J. M. and E. L. Sharp. 1978. Additive resistance in wheat to Puccinia striiformis. Phytopathology 68:1795-1799.

Kuhn, R. C., H. W. Ohm and G. E. Shaner. 1978. Slow leaf-rusting resistance in wheat against twenty-two isolates of Puccinia recondita. Phytopathology 68:651-656.

Luke, H. H., R. D. Barnett and P. L. Pfahler. 1975. Inheritance of horizontal resistance to crown rust of oats. Phytopathology 65:631-632.

Mashaal, S. F., Z. Kiraly, Z. Barabas and B. Barna. 1977. Laboratory, greenhouse and field methods for screening rust-resistant wheat cultivars. In: "Induced Mutations against Plant Diseases", IAEA, Vienna, Austria, p. 461-470.

Neervoort, W. D. and J. E. Parlevliet. 1978. Partial resistance of barley to leaf rust, Puccinia Hordei V. Analysis of the components of partial resistance in eight barley cultivars. Euphytica 27:33-39.

Ohm, H. W. and G. E. Shaner. 1975. Segregation for slow leaf rusting resistance in wheat. Agron. Abstr. 67:59.

Ohm, H. W. and G. E. Shaner. 1976. Three components of slow leaf-rusting at different growth stages in wheat. Phytopathology 66:1356-1360.

Parlevliet, J. E. 1975. Partial resistance of barley to leaf rust, Puccinia hordei. I. Effect of cultivar and development stage on latent per od. Euphytica 24:21-27.

Parlevliet, J. E. 1976. Partial resistance of barley to leaf rust, Puccinia hordei. III. The inheritance of host plant effect on latent period in four cultivars. Euphytica 25: 241-248.

Parlevliet, J. E. 1978. Further evidence of polygenic inheritance of partial resistance in barley to leaf rust, Puccinia hordei. Euphytica 27:369-379.

Parlevliet, J. E. and A. van Ommeren. 1975. Partial resistance of barley to leaf rust, Puccinia hordei. II. Relationship between field trials, micro plot tests and latent period. Euphytica 24:293-303.

Peterson, R. F., A. B. Campbell and A. E. Hannah. 1948. A diagramatic scale for estimating rust intensity on leaves and stems of cereals. Can. J. Res. (C), 26:496-500.

Shaner, G. and R. E. Finney. 1977. The effect of nitrogen fertilization on the expression of slow-mildewing resistance in knox wheat. Phytopathology 67:1051-1056.

Shaner, G., H. W. Ohm and R. E. Finney. 1978. Response of susceptible and slow leaf-rusting wheats to infection by Puccinia recondita. Phytopathology 68:471-475.

Simons, M. D. 1975. Heritability of field resistance to the oat crown rust fungus. Phytopathology 65:324-328.

Skovmand, B., R. D. Wilcoxson, B. L. Shearer and R. E. Stucker. 1978. Inheritance of slow-rusting to stem rust in wheat. Euphytica 27:95-107.

Sztejnberg, A. and I. Wahl. 1976. Mechanisms and stability of slow stem rusting resistance in Avena sterilis. Phytopathology 66:74-80.

Vanderplank, J. E. 1968. Disease Resistance in Plants. Academic Press. New York - London, 206 pp.

Vanderplank, J. E. 1978. Genetic and Molecular Basis of Plant Pathogensis. Springer-Verlag. Berlin - Heidelberg-New York. 167 pp.

Wahl, E., R. D. Wilcoxson and J. B. Rowell. 1980. Slow-rusting of wheat with stem rust detected in glasshouse. Plant Disease 64:54-56

Wilcoxson, R. D., A. H. Atif and B. Skovmand. 1974. Slow-rusting of wheat varieties in field correlated with stem rust severity of detached leaves in greenhouse. Plant Dis. Reptr. 58:1085-1087.

Wilcoxson, R. D., B. Skovmand and A. H. Atif. 1975. Evaluation of wheat cultivars for ability to retard development of stem rust. Ann. Appl. Biol. 80:275-281.

SPECIFIC AND NONSPECIFIC RESISTANCE TO STRIPE RUST AND LEAF RUST OF WHEAT

Roland F. Line
United States

Abstract

Eight types of stripe rust resistance have been identified based on infection types and disease intensity in the field and infection types on plants in various stages of growth at controlled temperatures. Two "slow rusting" types (R-type 4 and R-type 7) are especially important in western United States. Cultivars with R-type 4 are resistant to most races of Puccinia striiformis in the seedling to boot stages but become susceptible at heading to dough stages of growth. They are susceptible at all stages to other races; therefore, their resistance is race specific. R-type 7, the most effective stripe rust resistance in the U.S. is a high-temperature adult-plant resistance. Plants with R-type 7 are susceptible in the seedling stage to all races at all temperatures but become resistant in later stages at high temperatures. R-type 7 is present in many cultivars grown in northwestern U.S., has remained durable for 18 years, and is considered nonspecific. Techniques presently used to identify and evaluate cultivars and breeding lines for the above types of resistance will be described.

More than 99% of the wheat grown in northwestern U.S. consists of cultivars considered to be susceptible to leaf rust based on infection type in the field. However, rust increases slowly on a few cultivars. The slow rusting cultivars have fewer uredia/cm^2 of leaf surface, longer latent periods for rust development, fewer spores/uredium, and a range in size of uredia and lesions; especially at later stages of plant growth. Cultivars with this resistance show race-cultivar interactions for the above components, indicating that slow rusting in them is race specific. The possible use of slow rusting resistance to Puccinia recondita and techniques for identifying the resistance will be discussed.

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Stripe rust, caused by Puccinia striiformis West., and leaf rust, caused by Puccinia recondita Rob. ex. Desm., are the two most destructive foliar diseases of wheat in western United States. Since 1968, I have studied resistance to the rusts in field plots at sites in western United States where the rusts occur naturally, and in the greenhouse under controlled environmental conditions using specific races of the pathogens. When rust was present on cultivars and breeding lines in the plots, data on stage of plant growth, rust infection type, and rust intensity were recorded

Washington State University

periodically during the growing season. Urediospore samples were collected from plants at the sites and from fields in the region for evaluation on differential cultivars in the greenhouse. Resistance of seedling and adult plants was studied at 2-20C and 10-30C diurnal temperatures, programmed to simulate the low spring and high summer temperatures in the region. From the data, vulnerability of cultivars and breeding lines to races of the pathogens was determined, and the characteristics of various types of resistance were identified. Some of the results will be presented, and utilization of the various types of resistance will be discussed, especially in relation to an integrated disease control program.

Stripe Rust Resistance

Based on infection types and disease intensity in the field and at controlled temperatures at various stages of plant growth throughout the duration of rust establishment, the following resistance-types (R-types) have been identified: R-type 1, resistant or susceptible at all stages of growth and at both low and high temperatures throughout duration of rust establishment; R-type 2, initially resistant in the seedling stage but eventually susceptible, resistant at later stages in the field; R-type 3, variable resistance in the seedling stage, high resistance in later growth stages; R-type 4, resistant in the seedling stage, but susceptible in late stages of growth; R-type 5, susceptible, but the pathogen is slow to sporulate and consequently rust increases slower in the field; R-type 6, susceptible at low temperatures and resistant at high temperatures at all stages of growth; R-type 7, very susceptible at both low and high temperatures in seedling stage and at low temperatures in later stages; becomes more resistant in later stages when temperatures are high. R-type 8, susceptible at all stages, when rust intensity is low and when not under stress, but becomes more resistant when intensity is high or under moderate stress in the field.

Several of the types of resistance can be considered as "slow rusting." Two slow rusting types (R-type 4 and R-type 7) are especially important in western United States. Cultivars with R-type 4 are resistant to most races of *P. striiformis* in the seedling to boot stages, but become susceptible at heading to dough stages of growth. However, they are susceptible to other races at all stages. Therefore, their resistance is race specific. In contrast, R-type 7 (the most important type of resistance used in western United States) has shown no host-pathogen interaction under controlled conditions in the greenhouse and has remained durable in western United States for more than 18 years.

During the same period several cultivars with high race specific resistance to stripe rust have become vulnerable to new races of *P. striiformis*. Within three years after their release, new virulent races have attacked them.

Seedlings of cultivars with R-type 7 resistance are very susceptible at a wide range of temperatures, but as the plants get older, they become more resistant at high temperatures. However,

they remain susceptible when grown at low temperatures. At the high temperatures, flag leaves are more resistant than lower leaves. If plants are moved from a high temperature to a low temperature range, they become more susceptible. Cultivars differ in degree of temperature-sensitive, adult-plant resistance. Those with the highest degree of resistance also became resistant at an earlier growth stage.

Most of the common white and hard red winter wheats grown prior to 1950 had various degrees of R-type 7 resistance. In contrast, the club wheats (Elgin, Elmar, and Omar), with their limited genetic base, were very susceptible to stripe rust. Consequently, as they increased in production, stipe rust also increased in importance and during the late 1950s and early 1960s severe epidemics of stripe rust occurred. After the severe epidemic in 1960, there was a shift back to Brevor, with R-type 7. In subsequent years, Gaines and Nugaines, with even more effective R-type 7, were released. Since then, Gaines and Nugaines have been the major wheats in northwestern United States. In addition, Wanser and McCall (hard red winter wheats) were released in the mid 1960s and Luke, Hyslop, McDermid, Steph ns, and Daws (white winter wheats) were released within the last 7 years. All of these wheats have R-type 7 and some also have other types of resistance. These resistant cultivars have been grown for more than 18 years with no more-virulent races appearing on them, even though they are susceptible in the seedling stage to the predominant races in the region.

The following are some of the factors that made selection of cultivars with R-type 7 possible. a) The older popular cultivars had some degree of resistance. Thus, they were good parental material upon which to build. b) Selection for resistance was made in the field, under local environmental conditions, when plants were relatively mature (after heading) and when R-type 7 is most easily identified, rather than in the seedling stage or early in the growing season when the temperatures are low and R-type 7 cannot be identified. c) Only the most susceptible plants were discarded; plants with both intermediate and high resistance were saved. d) An extensive testing system at many sites was used to evaluate the new lines; emphasis was on improving yield under environmental conditions (including disease conditions) where the crop was to be grown. Superior cultivars adapted to various local conditions were often obtained even when knowledge of the local hazards was limited. Nugaines was released as a new cultivar primarily because its mean yield and test weight were slightly better than the yield of Gaines when tested at the various locations, even though it was not better at some locations. We now know from crop loss studies that the slightly better yield and test weights for Nugaines were due to slightly better R-type 7 to stripe rust.

These methods of selection should continue to be effective in developing improved wheats for the future. The methods increase the possiblity of obtaining types of resistance not iden-

tified on seedlings. However, identification of the types of resistance require disease measurement made several times during growth in the field; trap plots and rust collections to monitor pathogenicity of the rust; and tests with the cultivars under controlled conditions. If notes are recorded only once during the growing season, some types of resistance cannot be identified, and the interpretations may be different depending upon when the notes are recorded.

Monitoring virulence of the pathogens more accurately identifies the resistance-types. When Gaines and Nugaines were selected, pathogenicity of P. striiformis was limited to one or at most two races. Now, after the release of cultivars with specific resistance, several new races have appeared. A mixture of several races can influence interpretation of results obtained on plants that have resistance to some of the races but not to others. Also, if one race is present early and a second race appears later in the season (which happened in 1974), cultivars or lines with R-type 1 for the first race but not the second race will exhibit a pseudo R-type 4 resistance.

Plants with various types of resistance can be selected in the field but an understanding of the nature of the resistance can only be obtained by tests under controlled conditions. In the field, a high nonspecific R-type 7 may appear similar to the specific R-type 1. Race specificity can be determined by inoculating seedlings individually with different races. If seedlings are susceptible to races collected from the field, but the wheat line is resistant in the field, then there is reasonable assurance that the resistance is expressed only in older plants. If the line is susceptible to some races but not others, then it has specific resistance. However, it may or may not have other types of resistance. To identify other types of resistance, especially to a race or races not present in the field, plants in later stages of growth must be inoculated with a virulent race and evaluated at high and low temperatures to identify the existence of temperature-sensitive, adult-plant resistance.

Leaf Rust Resistance

Leaf rust has become more important in the Pacific Northwest since the early 1960s. More than 99% of the wheat acreage in the Pacific Northwest is planted with cultivars that are considered to be susceptible to P. recondita based on the infection type (size of the uredia and lesions). However, even though the cultivars are considered to be susceptible, rust increases more slowly on some cultivars than on others. Consequently, studies were made on the characteristics or components of slow rusting in local wheat cultivars to determine the interrelationships of components of resistance, and to determine the interactions of the components with races of the pathogen.

The components studied on adult and seedling plants were number of uredia/cm^2 of leaf surface, length of latent period,

number of spores/uredium, and infection type (size of uredia and lesions). Six of the nine cultivars studied had various degrees of slow rusting in the field. As measured by the above components, two cultivars expressed resistance only in the adult-plant stage, and four expressed resistance in both the adult and seedling stages. These four cultivars also showed race-cultivar interactions for the above components of resistance, which indicates that slow rusting in them is race specific. When cultivars had fewer uredia, longer latent periods, and fewer spores/uredum they also had a range of high to low infection types (large to small uredia and lesions). The association between a range of infection types and other components of resistance may be useful for selecting breeding lines that are slow rusting. Whether this type of resistance is more durable remains to be determined.

Management Wheat Diseases

Newer systemic fungicides show great promise for control of the foliar diseases of wheat when new races appear or as part of an integrated program using resistant cultivars, fungicides, and various crop management practices. The high-temperature adult-plant resistance is especially compatible with chemical control. For example, several of the new systemic fungicides are effective in delaying rust development when applied early in the season and some may even be effective as seed treatments. To prevent chemical residue in the harvested grain, it may not be desirable to spray late in the season. R-type 7 is most effective late in the season. Consequently, fungicides can provide early protection and resistant cultivars can provide later protection. Also many of the systemic fungicides are most effective under high rainfall conditions. These are the same conditions when rust is most severe. Other management systems that can be used will also be discussed.

EFFECTS OF FERTILIZERS ON SLOW RUSTING IN SPRING WHEAT

Roy D. Wilcoxson
Minnesota

Abstract

During 1973, 1974 and 1975 the development of Puccinia recondita Rob. ex. Desm. f. sp. tritici Eriks. & E. Henn. was studied, and durint 1976, 1977 and 1979 the development of P. graminis Pers. f. sp. tritici Eriks. & E. Henn. was studied in the wheat (Triticum aestivum L.) cultivars Marquis, Lee and Thatcher in a NPK factorial experiment at Rosemount, Minnesota. Each year of the test Marquis rusted rapidly with both rusts, Lee rusted moderately rapidly with both rusts, and Thatcher rusted slowly with stem rust and rapidly with leaf rust. The slow rusting characteristic of the cultivars was indicated by the area under the disease progress curve (AUDPC). The average values of AUDPC obtained in plots that received a fertilizer were compared with the values obtained in plots that did not receive the fertilizer. The effect of fertilizers on AUDPC varied with the chemical and the year of the test. NH_4NO_3 increased the average value of AUDPC due to leaf rust from 704 to 983 in 1975 but not in other years; it increased the average value of AUDPC due to stem rust from 588 to 645 in 1979 but not in other years. P_2O_5 increased the average value of AUDPC due to stem rust from 228 to 388 in 1977 but not in other years. K_2 reduced the average value of AUDPC due to leaf rust from 704 to 634 in 1973 but not in other years and it reduced AUDPC due to stem rust from 377 to 349 only in 1979. None of the other fertilizer treatments produced significant effects on slow rusting. Each year the interaction of cultivars with fertilizers was not significant statistically indicating that the slow rusting trait of the cultivars was not changed by the fertilizer treatments.

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Slow rusting in wheat has been known for many years (4), but it has not been systematically used as a source of resistance to the stem and leaf rusts though some effort to utilize it is made when breeders have selected lines that carried no more than a trace of rust at the end of a growing season. Most often race-specific resistance that is recognized by differences in infection type has been the basis of the breeding programs for rust resistance. However, during the last 10 years, interest in slow rusting has greatly increased because many people think it may be more stable than race-specific resistance.

Slow rusting is recognized by the ability of certain cultivars to delay infection, development and sporulation of rust during an epidemic. In individual plants the uredia are large and may or may not be associated with chlorosis, and the infection types indicate that the plants are susceptible in the seedling as well as in the adult plant stages of growth. Slow rusting is recognized by comparing disease progress curves or by comparing rust severity

Department of Plant Pathology, University of Minnesota

data collected during the logarithmic stage of disease development or at the termination of the epidemic (6, 10, 16, 18). Disease progress curves are especially useful in studies on slow rusting because they represent the effects of all factors on the development of the disease throughout the growing season. The comparison of disease progress curves may be facilitated by calculating different statistics from them (9, 18). I have found the area under the disease progress curve (AUDPC) to be useful because it has closely reflected what was observed about rust development in the field (18).

Slow rusting is known to occur in spring wheat (3, 9, 10, 16, 18), winter wheat (7) and durum wheat (17) infected with the stem and leaf rust pathogens. Inheritance of slow rusting with both pathogens has been documented (3, 13) and the stability of slow rusting has been studied in spring and winter wheats (3, 7, 18).

The effect of various environmental factors, and of races of the pathogens, on the slow rusting character deserves much more study than has been done. We know that slow rusting of some cultivars infected with stem rust may be modified by different races of the pathogen (12, 14), but more testing needs to be done using a genetic diversity of inoculum, and in international nurseries, before we can fully estimate the practical importance of races on slow rusting. We also know that slow rusting varies with the environments in which the tests are made (3, 6, 7, 18), but most authorities conclude that the relative differences in the cultivars are maintained throughout the several tests. Despite this conclusion, we need to continue testing the effects of environment on slow rusting because relatively few tests have been made.

Fertilizers constitute an environmental factor that varies greatly from field to field. Their effects on the susceptibility of wheat to stem and leaf rust is well known, but we do not know how they might influence slow rusting. In general, fertilization with nitrogen increases the susceptibility of plants to the rusts, but phosphorus and potassium tend to decrease the susceptibility. When these elements are used in a balanced fertilization program, phosphorus and potassium tend to overcome the adverse effects of nitrogen. The effects of fertilization on stem and leaf rusts have been summarized by Capetti _et al_., (1), Chester (2), Kiraly (5) and Stakman and Aamodt (15). The objective of this study was to observe the effects of fertilizers on the slow rusting characteristics of three spring wheats.

Materials and Methods

Factorial experiments were made at Rosemount, MN, with NH_4NO_3, P_2O_5, and K_2O, in a field that had been used annually as a factorial experiment for 11 years; each year the plots received the same chemicals as in previous years. During the 2 years prior to the start of these tests, the field was planted with oats without fertilization. The plots measured 7.7 X 19 m and there were four replicates. Each year 363 kg of NH_4NO_3, 312 kg of P_2O_5, and

335 kg of K_2O per hectare were scattered by hand on the appropriate plots before planting. Cultivars Lee, Marquis, and Thatcher (*Triticum aestivum* L.) were planted as a strip 2.4 m wide across each fertilizer plot.

The wheat cultivars were chosen because they are susceptible to the races of *Puccinia graminis* Pers. f. sp. *tritici* and *P. recondita* Rob. ex. Desm. f.sp. *tritici* studied, and because they differed in the rate at which they rust: Marquis rusts rapidly with both pathogens, Lee rusts moderately with both pathogens, and Thatcher rusts slowly with stem rust pathogen and rapidly with the leaf rust pathogen.

P. recondita f.sp. *tritici* races UN 2 and 7 developed in the plots in 1973, 1974, and 1975, but stem rust did not develop appreciably. *P. graminis* f.sp. *tritici* race 15 B2-TLM was used to inoculate the plots in 1976, 1977, and 1979 when plants were in the early boot growth stage. Leaf rust was kept out of the plots during these years by spraying 2-week-old plants and the ground around them with triazbutil (Indar) in water at the rate of 877 ml per hectare.

The severity of rust was evaluated once each week beginning about a week before inoculation. After the disease appeared in the field, rust severities were evaluated for 3 to 5 weeks with the aid of the modified Cobb scale (8). Rust severity data thus obtained were then converted to AUDPC (13) which was then used to indicate the slow rusting characteristic of the cultivars in the various fertilizer treatments. Analysis of variance was used to help interpret the significance of differences seen in the data. When the differences due to the fertilizers were statistically significant, the effect of an individual fertilizer was studied by comparing the average AUDPC values from all plots that received that fertilizer with values from all plots that did not receive it.

Results

The interaction between fertilizers and cultivars was statistically non-significant each year of the test, which indicates that the relative stability of the cultivars to leaf and stem rusts was not changed by the fertilizer treatments. In 1973, 1974, and 1975 leaf rust developed about equally in Marquis and Thatcher, but was significantly less in Lee, as indicated by the AUDPC values (Table 1). In 1976, 1977 and 1979 stem rust developed rapidly in Marquis, moderately rapidly in Lee, and slowly in Thatcher, as indicated by the AUDPC values (Table 1).

The effect of the fertilizers on slow rusting with both pathogens varied with the year as well as with the fertilizer treatment. In the leaf rust tests, fertilizers had a significant effect in 1973 and 1975, but not in 1974 (Table 2). In 1973, treatment of plots with K_2O significantly ($P = 0.05$) reduced the average value of AUDPC, but the other two fertilizers had no effect. In 1975, treatment of plots with NH_4NO_3 significantly ($P = 0.05$) increased the value of AUDPC, but the other two chemicals had no effect. In

Table 1. Average area under the disease progress curve when Lee, Thatcher and Marquis wheats were grown in an NPK factorial experiment and infected with *Puccinia recondita* f.sp. *tritici* and *P. graminis* f.sp. *tritici*.

Fertilizer[b]	Areas under Leaf Rust Progress Curve[a]								
	1973			1974			1975		
	Marquis	Lee	Thatcher	Marquis	Lee	Thatcher	Marquis	Lee	Thatcher
N	827	588	891	1143	936	1398	1008	892	1265
P	627	462	898	1168	1016	1443	674	417	647
K	685	435	720	1201	824	1488	970	493	923
NP	738	502	793	1223	971	1328	975	733	1062
NK	653	418	768	1233	866	1368	1095	938	1326
PK	753	418	780	1303	809	1443	923	529	867
NPK	843	400	760	1143	703	1202	855	589	1057
None	678	523	728	1348	1092	1488	734	464	715
Average	750	468	789	1220	903	1382	904	632	995
	Areas under the Stem Rust Progress Curve[a]								
	1976			1977			1979		
N	741	654	428	624	353	192	910	687	342
P	664	412	173	669	385	182	892	653	265
K	708	664	341	577	209	122	884	705	258
NP	804	683	260	541	354	208	954	705	387
NK	732	621	309	596	285	181	901	684	366
PK	639	440	163	631	295	173	875	600	314
NPK	746	659	241	641	311	199	875	579	356
None	776	713	206	622	336	164	831	622	278
Average	726	606	265	621	316	177	890	640	321

a/ Data based on 4 replicates each year. Statistically significant differences were: cultivars each year $P = .01$; fertilizers 1973, $P = .05$; 1975, $P = .01$; 1977, $P = .10$; 1979, $P = .05$. Areas under the disease progress curve are in arbitrary units and were calculated from three points on the disease progress curve in 1973, 1976, 1977 and 1979, from 5 points in 1974, and from 4 points in 1975. In 1973 - 1975 the disease was primarily leaf rust, but in 1976 - 1979 it was only stem rust.

b/ Fertilizers applied annually at the following rates: NH_4NO_3 at 363 kg per ha, P_2O_5 at 312 kg per ha, K_2O at 335 kg per ha.

Table 2. Effects of fertilization with N, P, or K on average area under the stem rust or leaf rust disease progress curve in wheat plots in different years.

Material	Fertilization Rate (kg/ha)	Area under disease progress curve[a] 1973	1974	1975	1976	1977	1979
NH_4NO_3	363	681	1118	983*	573	383	645*
	0	657	1219	704	492	363	588
P_2O_5	312	679	1146	788	490	388*	621
	0	659	1191	908	574	338	612
K_2O	355	634*	1124	897	522	349*	606
	0	704	1213	799	542	377	627

[a] For each year, the data are average values across all cultivars in plots that received or did not receive the indicated fertilizer. An asterisk on a data pair indicates that the effect of the fertilizer was statistically significant (P = 0.05). For data pairs without an asterisk, the differences were not significant.

the stem rust tests, the fertilizers had a significant effect in 1977 and 1979, but not in 1976 (Table 2). In 1977, P_2O_5 significantly (P = 0.05) increased the value of AUDPC and K_2O significantly decreased it, but NH_4NO_3 had no effect. In 1979 NH_4NO_3 increased (P = 0.05) the value of AUDPC, but the other two fertilizers had no effect.

Discussion

An effort was made to do the experiments in a field where large differences in fertility existed. The plots had been treated with the fertilizers for several years before the experiments were started, and during the 2 years previous to the tests, the field was not fertilized and was planted with oats. In addition, relatively large quantities of the fertilizers were applied to each plot. Observations on plant growth and yields indicated that the plots did indeed differ in fertility. In the plots that received the combination of the fertilizers, the plants were deep green in color and about 100 cm tall at maturity, whereas in those that received no fertilizers, the plants were light green in color and were about 76 cm tall. The annual yields were 269 to 405 kg/ha more in the fertilized plots than in those not fertilized.

This report also confirms previous observations that Lee rusts moderately rapidly with *P. graminis* f.sp. *tritici* and *P. recondita* f.sp. *tritici*, Marquis rusts rapidly with both pathogens, and Thatcher rusts slowly with the stem rust pathogen and rapidly with the leaf rust pathogen (3, 18). This behavior occurred in all of the fertility treatments, indicating that slow rusting is not readily changed by the fertilization practices.

This report on slow rusting, as well as the report of Shaner (11) on slow mildewing, suggests that this type of resistance is not easily affected by soil fertility. However, not many cultivars have been evaluated. It would be worthwhile to evaluate other wheat cultivars and lines in fertilizer tests to learn how universal the conclusion might be that soil fertility does not seriously affect slow rusting. Similar tests should be made with barley, oats, and corn.

Literature Cited

1. Capetti, E., S. Fosteris, E. Radulescu, V. Ionescu-Sisesti and F. Negulescu. 1964. Influenta densitatii semanatului si a ingrasamintelor chimice asupra comportarii unor soiuri de griu de toamna fata de rugini in cultura irigata. Nicolae Balescu Agron. Ser. A. 7:79-93.
2. Chester, K. S. 1946. The nature and prevention of the cereal rusts as exemplified in the leaf rust of wheat. Chronica Botanica Co., Waltham, MA. 269 pp.
3. Gavinlertvatana, S. and R. D. Wilcoxson. 1978. Inheritance of slow rusting of spring wheat infected by *Puccinia recondita* f.sp. *tritici* and host parasite relationships. Trans. Br. Mycol. Soc. 71:413-418.
4. Hayes, H. K., E. C. Stakman and O. S. Aamodt. 1925. Inheritance in wheat of resistance to black stem rust. Phytopathology 15:371-386.

5. Kiraly, Z. 1964. Effect of nitrogen fertilization on phenol metabolism and stem rust susceptibility of wheat. Phytopathol. Z. 51:252-261.
6. Nazareno, N.R.X. 1979. The adult plant resistance of Thatcher to stem rust. M.S. Thesis. University of Minnesota. 52 pp.
7. Ohm, H. W. and G. E. Shaner. 1976. Three components of slow leaf rusting at different growth stages in wheat. Phytopathology 66:1356-1368.
8. Peterson, R. F., A. B. Campbell and A. E. Hannah. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems of cereals. Can. J. Res. (C) 26:596-600.
9. Rees, R. G., J. P. Thompson and E. A. Goward. 1979. Slow rusting and tolerance to rusts in wheat. II. The progress and effects of epidemics in Puccinia recondita tritici in selected wheat cultivars. Aust. J. Agric. Res. 30:421-432.
10. Rees, R. G., J. P. Thompson and R. J. Mayer. 1979. Slow rusting and tolerance to rusts in wheat. I. The progress and effects of Puccinia graminis tritici in selected wheat cultivars. Aust. J. Agric. Res. 30:403-419.
11. Shaner, G. and R. E. Finney. 1977. The effect of nitrogen fertilization on the expression of slow mildewing resistance in Knox wheat. Phytopathology 67:1051-1056.
12. Skovmand, B., A. P. Roelfs and R. D. Wilcoxson. 1978. The relationship between slow rusting and some genes specific for stem rust resistance in wheat. Phytopathology 68:491-499.
13. Skovmand, B., R. D. Wilcoxson, B. L. Shearer and R. E. Stucker. 1978. Inheritance of slow rusting to stem rust in wheat. Euphytica 27:95-107.
14. Southern, J. W. 1978. The stability of the slow rusting character in nine spring wheat cultivars to five races of Puccinia graminis tritici in four Minnesota environments. Ph.D. Thesis. University of Minnesota. 162 pp.
15. Stakman, E. C. and O. S. Aamodt. 1924. The effect of fertilizers on the development of stem rust of wheat. J. Agric. Res. 27:341-379.
16. Staler, G. D., J. E. Watkins and J. Nordgaard. 1977. General resistance displayed by three hard red spring wheat (Triticum aestivum) cultivars to leaf rust. Phytopathology 67:759-762.
17. Statler, G. D., J. T. Nordgaard and J. E. Watkins. 1977. Slow leaf rust development on Durum wheat. Can. J. Bot. 55:1539-1543.
18. Wilcoxson, R. D., B. Skovmand and A. H. Atif. 1975. Evaluation of wheat cultivars for ability to retard development of stem rust. Ann. Appl. Biol. 80:275-281.

RELATIONSHIPS OF GENES CONDITIONING RESISTANCE TO *ERYSIPHE GRAMINIS* F. SP. *TRITICI* IN WHEAT

J. G. Moseman, P. S. Baenziger, and R. A. Kilpatrick
United States

Abstract

Many sources of resistance to *Erysiphe graminis* DC. f. sp. *tritici* Em. Marchal in wheat have been identified, and eight loci for resistance have been designated. The reactions of some sources of resistance to natural field infections or to special cultures in the seedling stage suggest that many additional, distinct genes for resistance are available in those sources. The two resistant varieties Khapli and Yuma and the two near-isogenic lines Khapli/8*CC and Yuma/8*CC, derived by backcrossing the resistant varieties Khapli and Yuma to the susceptible variety Chancellor, were studied to identify some of the suggested resistance genes.

Khapli has been the most resistant entry to the powdery mildew pathogen in the 1977 and 1978 Uniform Spring Wheat Powdery Mildew Nurseries and is resistant to all cultures of the pathogen maintained at Beltsville. Yuma, which was derived from Khapli, has been less resistant than Khapli in those two uniform nurseries and is susceptible to some cultures in our collection. The two near-isogenic lines have been susceptible to the powdery mildew pathogen at some locations where 1977 and 1978 Uniform Winter Wheat Powdery Mildew Nurseries were grown and to some cultures in our collection.

The reactions of progenies from crosses involving Khapli, Yuma, Khapli/8*CC, and Yuma/8*CC to cultures with specific virulence characteristics indicated that (1) Khapli has three genes for resistance, (2) Yuma has only two of the resistance genes present in Khapli, (3) the two derived near-isogenic lines have only one resistance gene, and (4) the four hosts all have gene Pm4.

The extra resistance genes in Khapli may explain why that variety has been more resistant than Yuma in the uniform nurseries and to our cultures of the pathogen. The extra gene in Yuma may explain why it has been more resistant than the near-isogenic lines.

Plant Genetics and Germplasm Institute, USDA-SEA, Beltsville, MD

The results illustrate (1) how cultures with specific virulence characteristics can be used to identify additional resistance genes and to show relationships between resistance genes in and between hosts, (2) that resistant varieties or lines derived from a resistant parent may possess fewer resistance genes than the original resistant parent, and (3) that when transferring multigenic resistance from a line with a different ploidy level to a susceptible variety, the backcrossing required to recover the susceptible variety's characteristics and ploidy level may result in a loss of resistance genes.

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The resistance of wheat, Triticum aestivum L. em Thell, to the pathogen Erysiphe graminis DC. ex Merat. f. sp. tritici Em. Marchal, which incites wheat powdery mildew, has been studied extensively. Genes for resistance to this pathogen have been identified at eight distinct loci on chromosomes of wheat (2, 3, 4, 5, 6). The loci have been designated Pm 1 through Pm 8 with three alleles at the Pm 3 locus. At six of the eight loci, genes from other Triticum species or rye, Secale cereale L., have been identified. Genes from T. timopheevi (Zhuk.), have been identified at loci Pm 2 and Pm 6, genes at loci Pm 7, and Pm 8 were derived from rye, and the genes at loci Pm 4 and Pm 5 were derived from T. dicoccum Schuebl. (1, 5, 6).

The effectiveness of genes in wheat for resistance to Puccinia recondita Rob. ex Desm. f. sp. tritici have been determined by their reactions in international nurseries. The genes Lr 9 and Lr 19 were shown to be more resistant than other Lr genes by analyzing their coefficients of infection in the International Wheat Rust Nurseries 1970-75 (8).

Relationships of genes conferring resistance to pathogens can be determined by inoculating individual F_2 plants with more than one culture of a pathogen. Genes for resistance to Erysiphe graminis DC ex. Merat. f. sp. hordei Em. Marchal at the Ml locus on chromosome 5 of barley, Hordeum vulgare L., were differentiated by inoculating F_2 plants with two cultures of the pathogen (7).

The objective of this study was to determine the number and relationship of the resistance genes conferring the resistance of the original T. dicoccum line 'Khapli' (1), T. durum Desf. line 'Yuma' which had Khapli as a parent and the two derived near-isogenic lines of cultivar 'Chancellor' (Cc), Khapli/8*Cc and Yuma/8*Cc, to cultures of E. graminis tritici. We will explain how the average coefficient of infection of five wheat lines in Uniform Wheat Powdery Mildew Nurseries and the reaction of these lines to infection with cultures having specific pathogenicity suggested to us the number of effective resistance genes in each line. We

will then show how the double and triple inoculating technique of infecting individual F_2 plants with two and three cultures confirmed, further identified, and demonstrated relationships between resistance genes, and that some resistance genes in the original lines were not transferred to the derived lines.

Materials and Methods

Selection of the five hosts was based upon their relationships and their reactions to the cultures of E. graminis tritici. The hosts were cultivar Chancellor (CI 12333), resistant lines Khapli (CI 4013), Yuma (CI 13245), and near-isogenic lines Khapli/8*Cc (CI 14123), and Yuma/8*Cc (CI 14124). The near-isogenic lines were derived by crossing Khapli and Yuma on Chancellor and then backcrossing seven times on Chancellor (1). Chancellor was susceptible to all the cultures of E. graminis tritici. The four resistant hosts, which have been reported to have gene Pm 4 conferring resistance to cultures (1), differed in their reactions to the cultures.

The three cultures of E. graminis tritici, 3, Ghemwat, and 4a were selected because they differed in pathogenicity on the four resistant hosts. Culture 3 was used to develop the two near-isogenic lines and gene Pm 4 had been shown to confer the resistance of the four resistant lines to that culture. Cultures Ghemwat and 4a differed in their pathogenicity, and also from the pathogenicity of culture 3 on the four resistant lines.

The plants for crossing and for producing F_1 and F_2 seed were grown in the greenhouse. The parents and F_2 seedling plants were inoculated with culture 3 when the first leaf had fully expanded and then were inoculated with the second culture 5 days later when the second leaf had expanded. Some F_2 plants were inoculated with a third culture 5 days after they were inoculated with the second culture when the third leaf expanded. Plants heavily infected with the cultures were gently shaken over the plants to be inoculated so that the conidiospores were uniformly distributed on the leaves of inoculated plants. The reactions of infections with culture 3 were read on the first leaf 7 and again 9 days after inoculation. Reactions to the second culture were read on the second leaf 5 days after the readings on culture 3 and 7 days after inoculation. Reactions to the third culture were read on the third leaf 5 days after the readings on the second culture and 7 and 9 days after inoculation. The infection types produced by the reactions were read on a 0 to 9 scale where 0-3 is highly resistant, 4-6 is resistant, and 7-9 is susceptible. The tests were conducted in a growing room maintained at 16-19C under 175 Einsteins $sec^{-1}m^{-2}$ of cool white fluorescent light 12 hours per day.

Results and Discussion

The average coefficients of infection to *E. graminis tritici* of the four resistant wheat lines and the susceptible check cultivars in the Uniform Wheat Powdery Mildew Nurseries (spring and winter) for 4 years are shown in Table 1. The four resistant lines had lower average coefficients than Chancellor or the susceptible checks suggesting that they may have genes which confer their resistance. Khapli had a lower average coefficient than Yuma, which suggested that Khapli may have an additional resistant gene not in Yuma. The average coefficients for the two derived near-isogenic lines were similar, suggesting that they may have the same genes conferring their resistance. Although the donor lines Khapli and Yuma were not in the same nurseries, the fact that their average coefficients were lower relative to the susceptible checks than were the average coefficients for the derived near-isogenic lines suggested that not all of the resistance genes were transferred from Khapli and Yuma to the near-isogenic lines.

Table 1. Average coefficients of infection of four wheat lines and susceptible checks in Uniform Wheat Powdery Mildew Nurseries 1976-1979.

	Average coefficients of infection							
	UWWPMN				USWPMN[1/]			
	1976	1977	1978	1979	1976	1977	1978	1979
Khapli		-	-		2.6	1.8	2.3	1.6
Yuma		-	-		2.5	10.1	11.1	7.8
Khapli/8*Cc	14.3	9.0	17.3	30[2/]		-	-	
Yuma/8*Cc	7.9	11.0	17.4	20		-	-	
Chancellor	30	40	44	46				
Susc. check	61	64	66	67	67	61	60	64

1/ Uniform Winter Wheat Powdery Mildew Nursery and Uniform Spring Wheat Powdery Mildew Nursery, respectively.

2/ This higher coefficient resulted from high value at one location. Many readings at that location were questionable, suggesting some error in planting or recording data.

The infection types produced by the reactions of the four resistant wheat lines and cultivar Chancellor with cultures 3, Ghemwat, and 4a of *E. graminis tritici* are shown in Table 2. Khapli was highly resistant to all three cultures. Yuma was highly resistant to cultures 3 and Ghemwat, but only resistant to culture 4a with an infection type 4. The two near-isogenic lines were highly resistant to culture 3, but only resistant to Ghemwat with an infection type 6, and were susceptible to culture 4a.

Table 2. Infection types produced by reactions of four wheat lines and one cultivar with cultures 3, Ghemwat and 4a of *Erysiphe graminis tritici*.

Lines or cultivar	Infection types with cultures			
	3	Ghemwat	4a	No. genes
Khapli	0	0	0	3
Yuma	0	0	4	2
Khapli/8*Cc	0	6	8	2
Yuma/8*Cc	0	6	8	2
Chancellor	8	8	8	0
Probable no. genes	1	2	2	

The zero infection types produced by the reaction of Khapli with the three cultures suggests that Khapli may have a minimum of one resistance gene which is effective in conferring resistance to all three cultures. The infection types produced by the reactions of Yuma with the three cultures suggests that Yuma may have a minimum of two resistance genes conferring its resistance. Yuma may have one resistance gene conferring the highly resistant reaction to culture 3 and Ghemwat, but that gene is not effective against culture 4a. A second gene in Yuma, however, may confer the resistant infection type 4 to culture 4a. The infection type produced in the reactions of the two near-isogenic lines suggests that they may have the same resistance genes conferring their resistance, because they produced the same reactions with three cultures. The near-isogenic lines may have one resistance gene conferring the highly resistant reaction to culture 3, but that gene is ineffective against the other two cultures. A second resistant gene, however, may confer the resistant infection type 6 to culture Ghemwat, but that gene is ineffective against culture 4a.

The zero infection types produced by the reactions of culture 3 with the four resistant lines suggests that the same resistance gene, Pm 4, may be conferring the resistance of those lines to culture 3 as reported previously (2). The infection types produced by the reactions of culture Ghemwat with the four resistant lines suggest that there may be two resistance genes conferring the resistance of those lines to culture Ghemwat. The zero infection types on Khapli and Yuma suggest that the same resistance gene may confer their highly resistant reactions, but that the gene is not in the near-isogenic lines. The two near-isogenic lines, however, may have another gene which confers the resistant infection type 6. The infection types produced by the reactions of culture 4a with Khapli and Yuma suggest that Khapli and Yuma may have two resistance genes conferring their resistance, and those genes are not in the two derived near-isogenic lines. The zero infection type produced on Khapli and the infection type 4 produced on Yuma by culture 4a suggest that Khapli may have a resistance gene conferring the highly resistant reaction that is not in Yuma. - Yuma has a resistance gene, however, which confers the infection type 4. The susceptibility of the near-isogenic lines to culture 4a suggests that they do not have either of those

resistance genes.

A comparison of the infection types produced by all of the lines with the three cultures of E. graminis tritici suggests that Khapli may have a minimum of three resistance genes each capable of producing a highly resistant infection type zero. The gene Pm 4 can be assumed to produce the highly resistant zero infection type produced by the reactions of the four resistant lines with culture 3, as previously reported (2). The resistance gene producing the highly resistant infection type zero of Khapli and Yuma by reactions with culture Ghemwat is not present in the near-isogenic lines which produce the resistant infection type 6. Therefore, that resistance gene is not Pm 4 but a different resistance gene in both Khapli and Yuma. The resistance gene producing the highly resistant infection type zero of Khapli with culture 4a is not present in Yuma or the two near-isogenic lines. Therefore, that gene is not Pm 4 or the gene conditioning the highly resistant zero infection type to culture Ghemwat but a third resistance gene present only in Khapli.

The reactions of F_2 plants from four crosses involving the four resistant lines to infection with culture 3 are shown in Table 3. The segregation of F_2 plants resistant and susceptible to infection indicates that the same gene confers the resistance of Khapli and Yuma and of the two near-isogenic lines and that the gene is dominant. That gene can be assumed to be Pm 4, which previously has been shown to confer resistance of those hosts to culture 3 (2).

Table 3. Reactions of F_2 plants from four crosses of four resistant wheat lines to infection with culture 3 of Erysiphe graminis tritici.

Cross	Reactions			Expected	P
	HR	R	S[1]	No. genes	
Khapli X Yuma	53	0	0	same	
Khapli/8*Cc x Yuma/8*Cc	300	0	0	same	
Khapli/8*Cc X chancellor	225	0	54	1 Dom	0.025-0.05
Khapli/8*Cc[2]/Chancellor	218	0	74	1 Dom	0.75-0.90

[1]Highly resistant, resistant, and susceptible, respectively.

The reactions of F_2 plants from four crosses involving the four resistant lines to infection with culture Ghemwat are shown in Table 4. The same resistance gene or genes were indicated as conferring the highly resistant reactions of Khapli and Yuma because all F_2 plants from the cross of those two lines were highly resistant. The same resistance gene or genes were indicated as conferring the resistant reactions of the two near-isogenic lines because all F_2 plants from the cross of those two lines were resistant. The gene conferring the resistant reaction of the two near-isogenic lines was demonstrated to be recessive.

Table 4. Reactions of F_2 plants from four crosses of four resistant wheat lines to infection with culture Ghemwat of *Erysiphe graminis tritici*.

Crosses	Reactions			Expected	P
	HR	R	S[1]	No. genes	
Khapli X Yuma	53	0	0	same	
Khapli/8*Cc X Yuma/8*Cc	0	150	0	same	
Khapli/8*Cc X Chancellor	0	34	106	1 res.	0.75-0.90
Khapli/8*Cc X Chancellor	0	38	108	1 res.	0.75-0.90

[1]Highly resistant, resistant, and susceptible, respectively.

The reactions of F_2 plants from four crosses involving the four resistant lines to infection with culture 4a are shown in Table 5. At least two resistance genes were indicated as conferring the resistance of Khapli. One gene was a dominant gene conferring the high resistance and a second gene which confers a resistant reaction which was also in Yuma. The two resistance genes were not in the two near-isogenic lines, because the two near-isogenic lines were susceptible to culture 4a.

Table 5. Reactions of F_2 plants from four crosses of four resistant wheat lines to infection with culture 4a of *Erysiphe graminis tritici*.

Crosses	Reactions			Expected	P
	HR	R	S[1]	No. genes	
Khapli X Yuma	42	11	0	2	0.25-0.50
Khapli/8*Cc X Yuma/8*Cc	0	0	150		
Khapli/8*Cc X Chancellor	0	0	139		
Yuma/8*Cc X Chancellor	0	0	146		

[1]Highly resistant, resistant, and susceptible, respectively.

The reactions of the F_2 plants from the four crosses involving the four resistant lines to infection with cultures 3 and Ghemwat are compared in Table 6. The reactions of the F_2 plants to the two cultures indicated that at least three different resistance genes are effective in conferring the resistance of those four lines to the two cultures. At least one resistance gene confers the highly resistant reaction of Khapli and Yuma to cultures 3 and Ghemwat. The resistance gene conferring the high resistance of Khapli and Yuma to culture 3 was probably the dominant resistance gene Pm 4 and also effective in conferring the highly resistant reactions of the two-isogenic lines. The gene conferring the highly resistant reaction of Khapli and Yuma to culture Ghemwat was not present in the two near-isogenic lines because they were only resistant to culture Ghemwat. Therefore, that gene is different from gene Pm 4. A third recessive resistance gene

Table 6. Comparison of reactions of F_2 plants from four crosses of four resistant wheat lines to infection with cultures 3 and Ghemwat of *Erysiphe graminis tritici.*

Cross	Culture	Reactions			Expected	P
		HR	R	S[1]	No.genes	
Khapli X Yuma	3	53	0	0	same	
	Ghemwat	53	0	0	same	
Khapli/8*Cc X Yuma/8*Cc	3	150	0	0	same	
	Ghemwat	0	150	0	same	
Khapli/8*Cc X Chancellor	3	34 + 86	0	20	1 Dom	0.005
	Ghemwat	0	34	20 + 86	1 Rec.	0.75-0.90
Yuma/8*Cc X Chancellor	3	38 + 71	0	37	1 Dom	0.90-0.95
	Ghemwat	0	38	37 + 71	1 Rec.	0.75-0.90

[1]Highly resistant, resistant, and susceptible, respectively.

conferred the resistance of the two near-isogenic lines to culture Ghemwat. That recessive resistant gene was probably closely linked with the dominant resistant gene Pm 4. All 34 F_2 plants resistant to Ghemwat were highly resistant to culture 3 and all 20 F_2 plants susceptible to culture 3 were susceptible to culture Ghemwat. The genes in the F_2 plants resistant to Ghemwat would be homozygous recessive and the genes in the F_2 plants highly resistant to culture 3 would include only the plants homozygous or heterozygous for the dominant resistance gene. The genes in the F_2 plants susceptible in culture 3 would be homozygous recessive and the genes in the F_2 plants susceptible to culture Ghemwat would include only the plants homozygous and heterozygous for the dominant susceptible gene.

The reactions of the F_2 plants from the four crosses involving four resistant lines to infection with cultures 3 and 4a are compared in Table 7. The reactions of the F_2 plants to cultures 3 and 4a indicated that at least three different resistance genes are effective in conferring the resistance of the four lines to those two cultures. As explained previously, the dominant resistance gene Pm 4 conferred the resistance of all four resistance lines to culture 3. The dominant resistant gene, which was indicated as conferring the high resistance of Khapli, was not present in Yuma because Yuma was only resistant to culture 4a. Therefore, that resistance gene was different from the resistance gene Pm 4. The resistance gene conferring the resistance of Khapli and Yuma to 4a was not present in the two near-isogenic lines because they were susceptible to culture 4a, and it was different from the gene or genes conferring the high resistance to Khapli.

The reactions of F_2 plants from the four crosses involving the four resistant lines to infections with culture 3, Ghemwat, and 4a are compared in Table 8. The reactions of the F_2 plants to the three cultures indicated that at least five different resistance genes are effective in conferring the resistance of the four lines to these three cultures. Resistance gene 1 was resistance gene Pm 4 which confers resistance to culture 3 and is not effective in conferring resistance to cultures Ghemwat or culture 4a. Resistance genes 2, 3, and 4 were the genes identified as conferring the resistance of Khapli and Yuma to cultures Ghemwat and 4a. Gene 2 conferred the high resistance of both Khapli and Yuma to culture Ghemwat. Gene 3 which conferred the high resistance of Khapli to culture 4a was not present in Yuma. Gene 4 conditioned the resistant reaction of both Khapli and Yuma to culture 4a. Resistance gene 5 was the recessive gene which conferred the resistant reactions of the two near-isognic lines to culture Ghemwat.

Table 7. Comparison of reactions of F_2 plants from four crosses of four resistant wheat lines to infection with cultures 3 and 4a of *Erysiphe graminis tritici*.

Cross	Culture	Reactions HR	R	S[1]	Expected No.genes	P
Khapli X Yuma	3	42 + 11	0	0	same	
	4a	42	11	0	1 + same	0.25-0.50
Khapli/8*Cc	3	150	0	0	same	
	4a	0	0	150	--	
Khapli/8*Cc X Chancellor	3	105	0	34	1 Dom	0.75-0.90
	4a	0	0	34 + 105	--	
Yuma/8*Cc X Chancellor	3	109	0	37	1 Dom	0.09-0.95
	4a	0	0	37 + 109		

[1]Highly resistant, resistant, and susceptible, respectively.

Table 8. Comparison of reactions of F_2 plants from four crosses of four resistant wheat lines to infection with cultures 3, Ghemwat, and 4a of *Erysiphe graminis tritici*.

	Cultures and No. Plants									No.Genes
	3			Ghemwat			4a			
	HR	R	S	HR	R	S	HR	R	S[1]	
Khapli X Yuma	53	0	0	53	0	0	42	11	0	3+1 Dom
Khapli/8*Cc X Yuma/8*Cc	300	0	0	0	150	0	0	0	150	2
Khapli/8*Cc X Chancellor	225	0	54	0	34	106	0	0	139	1 Dom+1 Rec
Yuma/8*Cc X Chancellor	218	0	74	0	38	108	0	0	146	1 Dom+1 Rec
No. genes		1 Dom			1 Rec + 1			1 Dom + 1		

[1]Highly resistant, resistant, and susceptible, respectively.

Conclusions

The following three conclusions can be drawn from this study:

1. Much information regarding resistance genes in resistant hosts is suggested by the average coefficient of infection of hosts in Uniform or International Disease Nurseries and by the reactions of resistant hosts to special cultures of pathogens. Relationships of resistance genes suggested by the average coefficient of infection of the four resistant wheat lines in the Uniform Wheat Powdery Mildew Nurseries (spring and winter) and by their reactions to infection with cultures 3, Ghemwat and 4a of E. graminis tritici were verified by the reactions of F_2 plants from crosses of those four lines to infections with the three cultures.

2. The double and triple inoculation technique of infecting the same F_2 plants with two or three cultures is an effective method for identifying additional resistance genes and for showing their relationships. In this study the resistance genes effective in conferring resistance against cultures Ghemwat and 4a were shown to be four distinct genes and were different from Pm 4 which confers resistance to culture 3.

3. Resistance genes in the original resistant parents are aften lost in lines derived from those parents. The original resistant tetraploid parent Khapli was shown to have five genes conferring resistance to the three cultures. The tetraploid line Yuma derived from Khapli had only four resistance genes. The resistance gene or genes which conferred the high resistance of Khapli to culture 4a was not transferred to the line Yuma. The two near-isogenic lines derived from Khapli and Yuma had only two closely linked resistance genes. The two resistance gener conferring resistance to culture 4a and the resistance gene conferring the highly resistant reaction to Ghemwat in Khapli and Yuma were not transferred to the two derived near-isogenic lines.

References

1. Briggle, L.W. 1966. Transfer of resistance to Erysiphe graminis f. sp. tritici from Khapli emmer and Yuma durum to hexaploid wheat. Crop Sci. 6:459-461.
2. Briggle, L.W. 1969. Near-isogenic lines of wheat with genes for resistance to Erysiphe graminis f. sp. tritici. Crop Sci. 9:70-72.
3. Jorgensen, J. Helms, and C.J. Jensen. 1973. Gene Pm 6 for resistance to powdery mildew in wheat. Euphytica 22:423.
4. Law, C.N. and M.S. Wolfe. 1966. Location of genetic factors for mildew resistance and ear emergence time on chromosome 7B of wheat. Can. J. Genet. Cytol. 8:462-470.
5. McIntosh, R.A. 1978. Breeding for resistance to powdery mildew in the temperate cereals. In the Powdery Mildews by D.M. Spencer. pp. 237-257.
6. Mc Intosh, R.A. Personal communication.
7. Moseman, J.G., and J. Helms Jorgensen. 1973. Differentiation of resistance genes at the Mba locus in six pairs of isogenic barley lines. Euphytica 22: 189-196.
8. Smith, R.T., and R.A. Kilpatrick. 1978. Effectiveness of genes for leaf rust resistance in international wheat rust nurseries, 1970-1975. Euphytica 27: 511-519.

NEW FUNGICIDES FOR CONTROL OF WHEAT LEAF RUST

J. E. Watkins and B. L. Doupnik, Jr.
United States

The Leaf Rust Problem

Worldwide wheat leaf rust caused by *Puccinia recondita* Rob. ex. Desm. f. sp. *tritici* Eriks is the principal foliar disease affecting wheat production (2). In Nebraska, leaf rust is one of three major foliar diseases of winter wheat, the others being Tan spot (*Pyrenophora trichostoma* (Fr.) Fckl. and Septoria leaf blotch or speckled leaf blotch (*Septoria tritici* Rob. ex. Desm.) (4,5,6).

Annual yield losses (5,6) in Nebraska's winter wheat due to foliar diseases are usually less than 5 percent but can be much higher when moderate, wet weather extends into late June and pathogen inoculum potential is high. In most years, however, the hot, dry, windy weather that usually prevails during this crucial post-boot stage is unfavorable for rust or leaf spot development. Occasionally, as in 1977, weather conditions from April to June are ideal for rust and leaf spot development and the yield may be much greater. In 1977, plots of Centurk winter wheat sprayed twice with mancozeb (Manzate 200) yielded 538 kg/ha (23.5%) more than the nontreated Centurk.

Factors Affecting Leaf Rust Severity

Winter wheat in Nebraska becomes infected in mid-to-late May by uredospores blown north from rusted fields in Kansas and Oklahoma (4). The severity of leaf rust is determined by the virulence of the rust population to the commonly grown wheat cultivars and by weather conditions favorable for infection and spread. Leaf rust will develop more rapidly in southeast and south central Nebraska due to higher moisture than in the dryer western wheat growing regions of the state. At least 95 percent of Nebraska's winter wheat acreage is planted to leaf rust susceptible cultivars (4,6).

Leaf rust evaluations are made during the growing season on winter wheat cultivars in small-grain variety tests located throughout Nebraska. Periodic monitoring of these trials help detect any rapid buildup of rust with enough advance warning to implement chemical controls. Under potential epidemic conditions, proper timing of protectant foliar fungicide applications will prevent rapid development and spread of leaf rust within local wheat growing areas. New protectant and systemic fungicides are being developed and tested and may offer more effective and economical means of control.

Foliar Fungicide Evaluations from 1977 through 1979

Fungicides were evaluated for control of wheat leaf rust in

Department of Plant Pathology
University of Nebraska

trials at the University of Nebraska's South Central Station, Clay Center, NE. In 1977 and 1978, plots consisted of Centurk winter wheat and in 1979 of Scout 66. Fungicide treatments were arranged in a randomized complete block design with four replications. Plot size varied from year-to-year. Fungicides were applied with a pressurized sprayer in 402 ℓ of water per hectare at mid-boot stage of growth followed by a second application in 7 to 14 days. Fungicide efficacy was measured by recording leaf rust severity on the flag leaf 10 to 14 days after final fungicide application. Yield and 1000-grain weight were determined.

Data presented in Tables 1, 2 and 3 includes only those fungicides which showed activity against P. recondita tritici and will be further tested. Other fungicides were evaluated but not listed here because they showed little potential for leaf rust control and the basic producers were no longer interested in further testing. Certain fungicides such as Bayleton, Indar and benomyl are commercially used for leaf rust control in Europe, the Middle East, South American and Mexico (1). However, in the United States, zineb is the only fungicide nationally registered for control of wheat leaf rust. In some states, including Nebraska, mancozeb has a special use registration for wheat leaf rust.

Leaf rust was moderately severe in 1977. Severity of leaf rust was significantly reduced for all treatments in Table 1 when compared with the check. Only trace amounts of leaf rust were found in plots treated twice with Bayleton and Bayleton + benomyl. Two applications of sisthane, zineb and benomyl + mancozeb gave excellent control. The remaining treatments were intermediate in control of leaf rust. Yield was not significantly different among all treatments.

Table 1. Chemical control of wheat leaf rust in south central Nebraska, 1977.

Treatment and rate (ai/ha)	Applications	% Leaf rust[1/]	Yield (kg/ha)
Bayleton 50W, 0.28 kg	2	Trace	2832
Bayleton 50W, 0.28 kg + Benomyl 50W, 0.28 kg	2	Trace	2711
Sisthane 36ED(36%ai), 0.56 kg	2	12.5	2354
Zineb 75W, 1.26 kg	2	16.2	2468
Benomyl 50W, 0.28 kg + Mancozeb 80W, 1.8 kg	2	18.7	2758
Bayleton 50W, 0.28 kg	1	27.5	2435
Mancozeb 80W, 1.8 kg	2	27.5	2805
Chlorothalonil 6F (54% ai), 1.8 kg	2	31.2	2099
Benomyl 50W, 0.28 kg	2	40.0	2455
Chlorothalonil 6F (54% ai), 1.2 kg	2	43.7	2408
Chlorothalonil 6F (54% ai), 2.4 kg	2	45.0	2388
Sisthane 36EC (36% ai), 0.28 kg	2	45.0	2435
No Treatment		62.5	2280
LSD 0.05		10.2	NS

1/Leaf rust severity recorded as % flag leaf with rust.

In 1978, leaf rust severity on the flag leaf was moderate. Leaf rust severity was significantly less than the nontreated check for all fungicide treatments in Table 2. Bayleton and CGA-64251 held rust levels to a trace, and severity on plots treated with sisthane, Bayleton + benomyl, benomyl + mancozeb and chlorothalonil was less than 10 percent. Grain yield of all treated plots was significantly higher compared with the nontreated check.

Table 2. Chemical control of wheat leaf rust in south central Nebraska, 1978

Treatment and rate (ai/ha)	Applications	% Leaf rust[1/]	Yield (kg/ha)
Bayleton 50W, 0.28 kg	1	Trace a[2/]	4130 ij
Bayleton 50W, 0.56 kg	1	Trace a	4157 i
Bayleton 50W, 0.56 kg	2	Trace a	3955 fgh
CGA-64251 0.864EC(0.1gai/ml), 0.24 kg	1	Trace a	4136 ij
CGA-64251 0.864EC(0.1gai/ml), 0.30 kg	1	1.0 a	3948 fghi
Sisthane 2ED(25%ai), 0.56 kg	2	1.1 a	3968 fghij
Bayleton 50W, 0.28 kg + Benomyl 50W, 0.28 kg	2	2.0 ab	3679 abcde
Benomyl 50W, 0.28 kg + Mancozeb 80W, 1.8 kg	2	5.0 abc	3955 fghi
Mancozeb 80W, 1.8 kg	2	5.2 abc	4002 ghij
Chlorothalonil 4F(40.4%ai), 1.8 kg	2	5.8 abcd	3915 fgh
Chlorothalonil 4F(40.4%ai), 1.4 kg	2	8.7 bcd	3773 bcdef
Chlorothalonil 4F(40.4%ai), 4.5 kg	1	9.3 cd	3820 cdefg
Zineb 75W, 1.7 kg	2	12.5 de	3867 defgh
No Treatment		30.0 h	3578 a

1/ Leaf rust severity recorded as % flag leaf with rust.
2/ Numbers in a column with a letter in common are not significantly different (DMRT P = 0.5).

In 1979, below normal precipitation during June slowed leaf rust development resulting in only a light severity. All fungicide treatments in Table 3 significantly controlled leaf rust. Grain yields were variable and not associated with leaf rust severity.

Bayleton, CGA-64250 and CGA-64251 in almost all trials kept leaf rust severity to a trace and have excellent potential for control of this disease. Excellent control was achieved with one application of CGA-64250 and CGA-64251 and two applications of Bayleton at rates much lower than those recommended for mancozeb or zineb. With the present RPAR (Rebuttable Presumption Against Registration - U.S. Environmental Protection Agency) status of mancozeb and zineb in the USA, it is imperative that new fungicides for control of wheat leaf rust be developed, evaluated and optimum application techniques be determined.

Control of *Puccinia recondita tritici* on Five Winter Wheat Cultivars with Indar

Indar is a highly specific systemic fungicide (3) with activity only against the wheat leaf rust organism *P. recondita tritici*.

Table 3. Chemical control of wheat leaf rust in south central Nebraska, 1979.

Treatment and rate (ai/ha)	Applications	% Leaf rust[1/]	Yield (kg/ha)
CGA-64250 3.6EC(0.42 g ai/ml), 0.25 kg	1	Trace	1560
CGA-64250 3.6EC(0.42 g ai/ml), 0.30 kg	1	Trace	1325
Bayleton 50W, 0.21 kg	2	Trace	1372
Bayleton 50W, 0.28 kg	2	Trace	1426
Bayleton 50W, 0.14 kg	2	2.0	1318
Benomyl 50W, 0.28 kg + Mancozeb 80W, 1.8 kg	2	2.5	1312
Mancozeb 80W, 1.8 kg	2	4.0	1378
Bayleton 50W, 0.21 kg	1	5.8	1378
Bayleton 50W, 0.28 kg	1	5.8	1318
No Treatment		18.8	1439
LSD 0.05		3.0	NS

[1/] Leaf rust severity recorded as % flag leaf with rust.

The present study was undertaken in 1978 to determine the efficacy of Indar on wheat leaf rust and the subsequent effect on grain yield.

Five winter wheat cultivars, Homestead, Scout 66, Buckskin, Lancota and Centurk were used for the study. Fungicide treatments were arranged in a randomized complete block design with four replications. Application rate was 0.3 kg/ha a.i. of Indar in 402 ℓ of water per hectare using a pressurized sprayer. When applied during the joint stage of plant growth, Indar significantly inhibited development of P. recondita tritici on the cultivars Homestead, Scout 66, Buckskin and Centurk (Table 4). Lancota is resistant to wheat leaf rust, therefore, differences between treated and nontreated plots would not be expected. Increases in grain yield due to treatment with Indar ranged from 2 percent in Scout 66 to 14 percent in Homestead.

There is little doubt that leaf rust is a potentially serious threat to wheat production. Under favorable weather and inoculum conditions, leaf rust rapidly develops to damaging levels on susceptible cultivars. Epidemics are difficult to forecast, but with diligent monitoring they can be detected sufficiently early for effective applications of fungicides.

LITERATURE CITED

1. Anonymous. 1978. Mayday for Mexico's wheat growers. Rohm and Haas Reporter 35:20-23.

2. Dickson, J.G. 1956. Diseases of field crops. McGraw-Hill Book Co., New York; Toronto, London. 517 p.

3. Von Meyer, W.C., S.A. Greenfield and M.C. Seidel. 1970. Wheat leaf rust: Control by 4-n-butyl-1,2,4-triazole, a systemic fungicide. Science 169:997-998.

4. Watkins, J.E., E.D. Kerr and B.L. Doupnik, Jr. 1977. Wheat leaf rust in Nebraska, 1976. Nebraska Farm, Ranch and Home Quarterly 24:16-17.

5. Watkins, J.E., B.L. Doupnik, Jr., E.D. Kerr and R.R. Carlson. 1979. Unchecked wheat disease can cause millions in losses. Nebraska Farm, Ranch and Home Quarterly 26:16-18.

6. Watkins, J.E., E.D. Kerr and B.L. Doupnik, Jr. 1980. Rust, leaf spot winter wheats costly foe. Nebraska Farm, Ranch and Home Quarterly 27:3-5.

Table 4. Control of wheat leaf rust on five winter wheat cultivars with Indar.

Cultivar/Treatment	% Leaf rust[1/]	Yield (kg/ha)	(%) Increase
Homestead nontreated	32.5	1675	
Homestead treated	1.1	1957	14.4
LSD 0.05	8.6	437	
Lancota nontreated	1.6	1749	
Lancota treated	0.5	1695	- 3.1
LSD 0.05	1.8	67	
Centurk nontreated	67.5	1661	
Centurk treated	7.9	1762	5.4
LSD 0.05	16.3	134	
Buckskin nontreated	63.7	1850	
Buckskin treated	4.5	2072	10.7
LSD 0.05	8.1	209	
Scout 66 nontreated	62.5	1688	
Scout 66 treated	3.4	1722	2.0
LSD 0.05	4.7	282	

[1/] Leaf rust severity recorded as % flag leaf with rust.

EFFECT OF LEAF RUST (PUCCINIA RECONDITA) ON FORAGE PRODUCTION FOR LIVESTOCK GRAZING OF WINTER WHEAT

H. C. Young, Jr. and R. D. Morrison
United States

Abstract

In the southern plains of the United States 50 percent of the winter wheat is uniquely used for both livestock grazing and grain yield. Wheat for these dual purposes is seeded up to 2 weeks earlier than optimum for maximum grain production. Therefore, there is a longer leaf rust development season, often resulting in severe epidemics in the autumn. These epidemics reduce growth of wheat and reduce the grazing capacity. Measurements of the effect of rust on growth were made using sprays, isogenic lines and both resistant and susceptible cultivars in 8 experiments at 4 locations during 3 years. 'Indar', 17 to 70 gms/ha, controlled rust but yields were reduced though not significantly. The resistant isogene yielded significantly higher than the susceptible isogene in 3 of 8 experiments where rust severities were highest. Resistant cultivars as a group yielded significantly higher than the susceptible cultivar group in 4 of 8 experiments, again where rust severities were highest. The mean yield of the resistant group in all 8 studies was 32 percent higher than the susceptible group. In the experiment with the highest rust severity the resistant group was 58 percent higher than the susceptible group.

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Introduction

Control of plant disease for the purpose of measuring loss of yield due to disease has been most commonly done by the use of chemicals, isogenic cultivars, or cultivars resistant and susceptible to the disease (4). All of these methods have advantages and disadvantages, and the most effective control generally depends upon the disease being studied. All 3 of these controls were available and were used in this study.

Leaf rust of wheat (*Puccinia recondita* Rob. ex Desm. f. sp. *tritici* Eriks.) has long been a major pest in the southern plains of the United States (2,3) and remains so today. Twenty to 30 years ago wheat was seeded from early to mid-October through that region, which was optimum for grain yield. Leaf rust made minimal development in the autumn under those conditions. In more recent years, however, it has become a profitable practice to use wheat for livestock grazing throughout the autumn and winter seasons, as well as for grain yield. Now, over 50 percent of the planted wheat is grazed in the southern plains region of the U.S., and to accomodate greater forage growth during this period wheat is

Oklahoma State University, Stillwater

seeded up to 2 weeks earlier. This, of course, allows a greater development period for leaf rust, and epidemics sufficiently severe to lower grazing capacity (normally 1 animal per hectare) occur somewhere in the region in 7 of 10 years, and region-wide epidemics occur on an average of 1 in 5 years. To accomodate such vagarities in epidemic development, 8 studies were made at 4 locations in the state of Oklahoma over a period of 3 years. Data for each specific experiment are reported elsewhere (11).

Although the ultimate aim was to determine the effect of leaf rust on the grazing capacity of wheat, the use of animals as a yield measurement is cumbersome, costly and often quite inaccurate unless plots are very large. Therefore, we developed a method of clipping and collecting the leaves that would partially simulate grazing.

Materials and Methods

Each plot consisted of 4 rows 3 meters long. Two and one half meters of one center row were clipped for forage yield and the other row was later harvested for grain yield. Some experiments were randomized blocks with 4 replications; others were 8 by 8 latin squares. Each entire plot was surrounded by a border of a susceptible cultivar which was inoculated on the windward (south) side of the plot by brushing the plants at about 14 to 21 days of age with pots of plants infected with leaf rust (1). These inoculations were made in late evening and the plants then were sprayed with water and a surfactant.

The plots to be sprayed with a rust control chemical were planted with a widely grown and universally susceptible cultivar, 'Danne', CI 13876. The material used for spraying was 'Indar', which has been reported to be effective for the control of leaf rust (5), but not for any other diseases of wheat. It was used in 6 experiments at various rates from 17 gms to 70 gms per hectare. It was sprayed on the plots within 14 days after seeding with a back-pack sprayer and in 2 experiments it also was used as a seed treatment. In order to assure adequate distribution over small plots more water (approximately 500 l/ha) was used than normally would be used for spraying large fields, particularly by air.

A pair of isogenic lines was used which had been developed previously by crossing the cultivar 'Transfer', CI 13483, containing the gene LR9 (7) with the adapted susceptible cultivar 'Comanche' CI 11673; backcrossing to 'Comanche' 4 times and selecting pairs of plants in the F3 of the 4th backcross. The final pair selected was equal in forage and grain yields for three years in tests in the absence of rust. Although there are now isolates of leaf rust with pathogenicity on LR9, this gene remained effective throughout these tests.

Many other cultivars were used in the tests that were classified as either resistant, intermediate or susceptible depending upon the severity of leaf rust, measured by the modified Cobb Scale, that developed on them.

A device to clip the leaves was made by placing a battery operated sissors-type clipping machine mounted on 2 boards 2 cm thick by 5 cm wide mounted vertically 7.5 cm apart. The clippers were mounted in the center of the boards which were 50 cm long. Metal pans 15 cm wide were attached to the outside of the boards on each side and were shaped to a point near the board in front in order to raise the documbent leaves into the clippers. The clipped leaves were depos ed in the pans and transferred to plastic bags when the pans became full. These bags of leaves were weighed immediately and the leaves later transferred to paper bags for drying at 60C. The dried clippings also were weighed, but only the wet or fresh weights are reported here since our machine harvested the dead and already dried rusted leaves, which livestock normally do not harvest, as well as the fresh healthy leaves.

Generally 2 clippings were made, although in 2 experiments 3 clippings were made. The first clipping was usually about 30 days after seeding and the second clipping 14 days later. However, clipping time depended upon growth and the clippings usually were made after the unclipped portions of leaves were approximately 15 cm or more in length.

Results

Severe epidemic leaf rust development occurred in 3 experiments and critical rust severity occurred in 2 others of the 8 experiments made. Epidemic development depended more upon ambient moisture and temperature than on the fact that the experiments were inoculated.

When sprayed and unsprayed plots were compared the unsprayed plots yielded more than the sprayed plots in all tests except where the rust was most severe, although none of these differences were statistically significant. This was true even though control of the disease was excellent. In general, the higher the rate, the greater the difference between sprayed and unsprayed. The most extreme difference noted was when Indar was used in two experiments at 2 rates as a seed treatment. In this case the higher rate had a significantly lower forage yield than the untreated or unsprayed control. With this method of disease control, there appeared to be no increase in forage yield as a result of controlling leaf rust.

In the experiments where severe rust epidemics occurred the resistant isogene yielded significantly higher than the susceptible isogene. Differences between the 2 isogenes ranged from 17 to 69 percent, indicating with this method of disease control a marked decrease in livestock carrying capacity as a result of leaf rust damage.

When the yields of resistant cultivars as a group were compared with intermediate and susceptible cultivars as groups, there also were significant differences in the 5 experiments where leaf rust severities were highest or where rust developed at a critical

period. This occurred despite the fact that there were inherent differences in forage growth capacity between cultivars within and between groups. Differences between the resistant and susceptible groups ranged from 11 to over 59 percent with the intermediate group generally falling between, as would be expected. It should be pointed out that even in years of light rust, if the infected plants were small, significant damage occurred, as in the 1975-Tipton experiment where the difference between resistant and susceptible groups was 41 percent. This has been confirmed by Pyzner (6) and by Vanitchayangkul (8) in growth chamber studies. Also, in the 1976-Stillwater experiment the intermediate group yielded the highest in spite of higher rust severities than the resistant cultivars. This was caused by one unusually high yielding cultivar in the intermediate group. Such results can be expected with experiments of this type.

As an overall average of all experiments, the first clipping yielded more than the second. The damage due to rust expressed as a comparison between the resistant and susceptible cultivar groups was 21 percent in clipping one and 29 percent in clipping two. Williams (9) and Williams and Young (10) confirmed that rust has a serious effect on root growth in the seedling stage and therefore hampers the recovery of the plant from clipping.

Comparing all 3 methods of evaluating the losses in foliar growth due to rust then, we found that spraying with Indar, even though rust was essentially controlled, produced no advantage in growth over the control. However, comparing the means of the resistant and susceptible isogenes in all tests we found that on the average the susceptible one yielded only 77 percent of the resistant one. Similarly, when the resistant group of cultivars was compared to susceptible group, the latter yielded only 76 percent as much as the resistant group. Since these figures are so close, we believe that the data present a reasonable estimate of the damage to foliar growth caused by rust over the period that these studies were made. We have, therefore, calculated a regression coefficient using the means of the yield of the resistant, intermediate and susceptible groups in each experiment together with the corresponding mean rust severities. That coefficient was found to be -11.62. In the one experiment with the most severe epidemic of leaf rust the coefficient was -18.12.

Literature Cited

1. Browder, L. E. 1971. Pathogenic specialization in cereal rust fungi, especially *Puccinia recondita* f. sp. *tritici*: concepts, methods of study and applications. U.S. Dept. of Agr. Tech. Bull 1432. 51 pp.

2. Chester, D. Starr. 1939. The 1938 wheat leaf-rust epiphytotic in Oklahoma. Plant Dis. Reptr. Supple. 112. 19 pp.

3. Chester, K. Starr and D. A. Preston. 1947. Another epiphytotic of fall wheat leaf rust in the southwest. Plant Dis. Reptr. 31:15-17.

4. James, W. Clive. 1974. Assessment of plant diseases and losses. Ann. Rev. Phytopath. 12:27-48.

5. Pyzner, John Ray. 1975. Effect of leaf rust infection on the growth of wheat seedlings. Master of Science degree thesis. Oklahoma State University, Stillwater, OK. 29 pp.

6. Sears, E. R. 1956. The transfer of leaf-rust resistance from Aegilops umbellulata to wheat. Brookh. Symp. in Biol. 9:1-22.

7. Vanitchayangkul, Suree. 1973. Relation of leaf rust severity to growth of young wheat plants. Master of Science degree thesis. Oklahoma State University, Stillwater, OK. 40 pp.

8. von Meyer, W. A., S. A. Greenfield and M. C. Seidel. 1970. Wheat leaf rust; control by 4-n-butyl-1,2,4-triazole, a systemic fungicide. Science. 169:997-998.

9. Williams, Ervin, Jr. 1973. Effects of Puccinia recondita f. sp. tritici on certain nutritive values and forage yields of winter wheat. Doctoral degree thesis. Oklahoma State University, Stillwater, OK. 68 pp.

10. Williams, Ervin, Jr. and H. C. Young,Jr. 1973. Effect of Puccinia recondita f. sp. tritici on winter wheat forage. Proc. Okla. Acad. Sci. 53:69-72.

11. Young, H. C., Jr., and R. D. Morrison. 1980. Effect of leaf rust on grazing capacity of winter wheat. Okla. Agr. Exp. Sta. Tech. Bull. (In manuscript).

BREEDING FOR RESISTANCE TO THE BARLEY YELLOW DWARF VIRUS

C. W. Schaller and C. O. Qualset
United States

Abstract

Barley yellow dwarf virus (BYDV) is recognized as an important disease in most of the major cereal producing areas of the world, with losses ranging from 20 to 30 percent reported in some areas. Greater losses have generally been reported for barley and oats, than for wheat. However, many researchers believe losses for wheat are as great or greater, but infection may go undetected due to more limited symptom expression on wheat. Our experimental evidence indicated that losses for barley and wheat are approximately equal when tested under comparable conditions. Recent renewed interest in the disease would suggest that the disease either is becoming more widespread in distribution, has increased in the severity, or is being accurately identified by more research workers.

BYDV is transmitted by several species of aphids. Aphid control has not been effective in eliminating infection, and although certain cultural practices, i.e. adjusting planting dates, may help to minimize yield losses, development of resistant cultivars offers the only positive method of controlling the disease and reducing yield losses. Sources of resistance are available in barley, oats, and wheat, although the level of tolerance in wheat, comparable to that in the other two crops have not been found and appears to be more complex.

Research programs directed toward the identification of sources of resistance and, subsequently, the development of resistance cultivars, have been underway at the University of California, Davis, since the disease was first described in 1951. Activities have centered mainly on wheat and barley. Satisfactory inoculation techniques for screening populations under field conditions have been developed, utilizing early planted plots for intercepting aphid flights and subsequent increase of both the virus and vectors during the winter months. Test plots are planted adjacent to the aphid trap in the late spring so that the test plants are in the three-leaf stage when the aphid population are at a maximum. Test plants are inoculated by cutting aphid bearing plants and scattering them over the test plots. Symptom expression, discoloration and dwarfing, between tolerant and susceptible barleys is usually sufficiently distinct to allow accurate classification. Although differences in symptom expression in wheat are less striking, disease ratings, based on single-plant scoring of spaced material, is fairly effective. Differential disease rating and productivity of paired plots, utilizing systematic insecticides to control the vector and minimize infection also have been used successfully.

Department of Agronomy and Range Science, University of California, Davis, California,

Several thousand entries of wheat and barley from the USDA world collection have been screened for resistance. Satisfactory resistance was found in the Ethiopian barleys, which was found to be conditioned by a single major gene ($\underline{Yd_2}$). Comparable levels of resistance have not been found in wheat, although limited tolerance was found in both tetraploid and hexaploid wheats. Tolerant x tolerant crosses gave progenies with better scores than the parents, indicating quantitative inheritance. Anza wheat, a highly successful cultivar with considerable tolerance was selected from a complex cross involving several parents, and evidence suggests that significant advances can be made in developing highly tolerant cultivars by recurrent selection in populations derived from crosses involving the best tolerance available.

Tolerant cultivars of both wheat and barley are available for production in California. The protection afforded by these cultivars is indicated by the differential performance of tolerant and susceptible cultivars under experimental conditions, utilizing systematic insecticide to control the vectors and minimize infection. In the check plots, yield of the susceptible wheat cultivar, Ramona 50, was reduced by 51% and the susceptible barley cultivar, Atlas 57, by 40%, whereas the yield of the tolerant wheat cultivar was reduced by 20%, with no measurable reduction with the resistant barley cultivar, Atlas 68.

The above difference in response between the tolerant wheat and barley cultivars is indicative of the differences in levels of resistance between the two crops. Since the higher tolerance found in barley is conditioned by a major gene ($\underline{Yd_2}$), an attempt is underway to transfer this gene from barley to wheat. F_1 generation plants of the second backcross to wheat have been produced and will be used in additional crosses to wheat. It is too early to predict whether this transfer will be successful and if the $\underline{Yd_2}$ gene will be effective in a wheat genotype.

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Barley yellow dwarf virus disease (BYDV) is recognized as an important cereal disease in most of the major cereal producing areas of the world, with significant economic losses being reported from many areas (Schaller and Qualset, 1978). Losses to the California barley crop, resulting from the first recorded outbreak of the disease in 1951, were estimated at 10 percent (Oswald & Houston, 1953). In the United States, the disease rose to national prominence in 1959, when its economic impact on oat production was equated to the losses from Victoria blight and crown rust in the years when those diseases were most serious (Murphy, 1959). Economic losses have been reported in Canada (Gill, 1965), in England (Doodson, and Saunders, 1970), and in New Zealand (Smith, 1967). Greater losses have generally been reported for barley and oats, than for wheat. However, many researchers believe losses for wheat are as great or greater, but

infection may go undetected due to more limited symptom expression on wheat. Our experimental evidence indicated that losses for barley and wheat are approximately equal when tested under comparable conditions.

Recent renewed interest in the disease would suggest that the disease either is becoming more widespread in distribution, has increased in the severity, or is being accurately identified by more research workers. Participants in the BYDV Workshop held at Urbana, Illinois in 1977 estimated average annual losses of 1 to 3% of the total wheat, barley and oat production in the United States and Canada, with losses of 20 to 30 percent in some areas (unpublished). Researchers in attendance at the Conferencia Regional de Cerales, Quito, Ecuador, 1978 (proceedings in press) stressed the importance of BYDV in all major cereal producing areas in South America. With the present widespread interest in the disease, it is appropriate and timely to establish international programs to coordinate the research activities on BYDV with respect to wheat, barley, oats and triticale. CIMMYT is making an effort to develop an international cooperative program to enhance progress in breeding for resistant cultivars in wheat, triticale, and barley.

Fourteen species of aphids are known to be vectors (Slykhuis, 1967). Of special interest to those working on disease resistance is the difference in transmission efficiency among the different species and the existence of vector-specific strains (Rochow, 1959, 1961, 1972; Toko and Bruehl, 1959, and others). Both vector-specific and non-specific strains have been identified.

Differences in pathogenicity among isolates of the virus have been demonstrated by their relative virulence on different cultivars of oats, wheat and barley, by their ability to infect different grass species, and by symptom expression. (Allen, 1957; Bruehl and Toko, 1957; Catherall & Hayes, 1966; Gill, 1967; Rochow, 1959; Smith, 1967; Watson and Mulligan, 1960.) Reversals of disease reaction have been observed when cultivars of barley were tested at different locations (Arny and Jedlinski, 1966; Hayes, Catherall and Jones, 1971; Schaller et al. 1963.) The significance of these reversals, as they relate to the development of resistant barley cultivars, will be discussed later.

Symptoms are not so pronounced in wheat as in barley or oats. Bruehl (1961), Rochow (1961), and Wiese (1977) have described and illustrated in detail the various symptom expressions. Differential expression reflects the complicated interactions among the three biological systems involved - the virus, the vector and the host - together with environmental effects. Leaves of plants infected in the seedling or later stages show yellowing or reddening. Dwarfing is evident, mainly after seedling infection. The number and fertility of headed tillers are reduced, flowering is delayed, inflorescence size, kernel weight and the number of kernels per head are reduced, resulting in reduced plant productiv-

ity (Bruehl, 1961; Gill and Buchannon, 1972; Oswald and Houston, 1953; and others). All of these criteria have been used by various researchers in assessing field losses and in determining plant or cultivar reaction.

Resistant cultivars offer the only effective method of reducing losses from BYDV. Aphid control is not effective in eliminating infection as only momentary feeding by the vector is sufficient for transmission of the virus. Insecticidal control of aphids has been effective in reducing the amount of damage in some instances by preventing secondary spread of the virus from the initial foci of infection (Close, 1970). Yield losses can be reduced by avoiding early fall or late spring planting in most areas because of the high probability of aphid infestation on seedling plants at those periods. Fall infection of winter wheat caused greater yield reductions (81%) than spring infection (62%) in controlled inoculation studies in South Dakota (Fitzgerald and Stoner, 1967). Early infection normally causes greater yield reduction than late infection (Bruehl, 1961; Doodson and Saunders, 1970; Gill, 1967; Oswald and Houston, 1953; Smith, 1967). However, under certain conditions, greater yield losses and stronger symptom expression may result from infections at later growth stages (Price and Stubbs, 1963; Smith, 1967). Jones and Catherall (1970b) have suggested that some BYDV strains are adapted to early infection and others to late infection.

Significant progress has been made in developing BYDV tolerant barley and wheat cultivars for California and the remaining portion of the paper will deal mainly with these programs.

Tolerant barley cultivars are available for production in all areas of California. Increased annual productivity attributable to resistance is estimated at 10 to 15%. Although a comparable level of tolerance has not been found in wheat, the productivity and popularity of the wheat cultivar, Anza, which was grown on 53% of the wheat acreage in California in 1977, can be attributed in part to its tolerance to BYDV. The protection provided by the tolerant commercial cultivars is indicated by the differential performance of tolerant and susceptible cultivars under experimental conditions.

For example, we have used a systemic insecticide (Thimet-disulfoton) applied with the seed at planting time to reduce vector feeding and thereby minimize the effects of BYDV. The data presented in Tables 1 and 2 show the yield results from a late spring planted trial conducted at Davis for four years. The grain yield of the susceptible wheat cultivar Ramona 50 was 51% higher when treated with Thimet than the untreated control, whereas the tolerant cultivar, Anza, when treated, was only 20% higher than the control (Table 1).

In the same tests, the yield of the treated susceptible barley cultivar, Atlas 57, was 40% higher than the control with no measurable difference in the resistant cultivar, Atlas 68. Data presented in Tables 1 and 2 also provide an indication of

the differential level of available tolerance between wheat and barley. The minimum observed difference between the treated vs. the non-treated (control) plots for wheat was about 20% for the varieties Anza, Inia 66R, Lerma Rojo 64, and CI 13232 (Table 1). The barleys were much less affected than wheat, with differences ranging from -1 to 10% (Atlas 68, CM 67, and Sutter; (Table 2). The differences in yield between treated and untreated plots are believed to be due primarily to a degree of control of BYDV as indicated by the generally lower BYDV scores in the treated cultivars (Tables 1 and 2). It should be pointed out, however, that systemic insecticides can affect yields of grain and forage (Stanley and Qaulset, 1968), with some cultivars of winter wheat and winter barley showing increase and others decrease in yield.

Table 1.

Effect of Thimet on BYDV Symptoms and Grain Yields: 4-Year Means
Wheat and Atlas Barley

Variety	BYDV Score		Yield Kg/Ha		
	T	NT	T	NT	T/NT(%)
Anza	1.8	3.0	3230	2690	120
CI 13232	1.7	2.6	2380	2000	119
Ramona 50	5.1	6.8	2390	1580	151
INIA 66R	3.8	5.4	3080	2590	119
Sonora	4.0	6.2	3040	2350	129
Lerma Rojo	4.6	6.1	2820	2330	121
Oviachic 65	2.6	4.2	2400	1750	137
Atlas 57 Barley	4.8	6.7	3450	2350	146
Atlas 68 Barley	1.8	2.0	4910	4620	106

T = soil treated at planting; NT = no soil treatment.

Table 2.

Effect of Thimet on BYDV Symptoms and Grain Yields: 3-Year Means
Barley

Variety	BYDV Score		Yield Kg/Ha			Susc/Res. (%)	
	T	NT	T	NT	T/NT(%)	T	NT
Atlas 57	4.9	6.1	3390	2490	136	75	55
Atlas 68	1.8	1.6	4530	4500	101		
Cal. Mariout	4.7	6.0	3100	2330	133	80	66
CM 67	2.3	2.6	3880	3530	110		
Sutter	0.9	0.9	4660	4690	99		

T = soil treated at planting; NT = no soil treatment.

Screening Methods

Inoculation methods have been developed at Davis which produce infection levels of sufficient intensity to permit satisfactory field evaluation of parental and segregating populations (Rasmusson and Schaller, 1959). Plots (aphid traps) of susceptible barley, wheat, and oat cultivars are planted in a mixture adjacent to the test area at two-week intervals early in the fall. These plots intercept late fall flights of the aphid vector and provide host plants for the increase of both the virus and vectors during the winter months. Rhopalosiphum padi (L.), R. maidis (L.), and Macrosiphum avenae (Fabricus) are the major aphid species naturally infesting the trap plots. The barley and wheat plantings are made so that the test plants reach the desired growth stage (3 - leaf) when the aphid population in the adjacent traps are at a maximum. The test plants are inoculated by cutting the aphid-bearing plants and scattering them over the test plots. Vigorous shaking helps to dislodge the aphids which subsequently crawl to the plants. In most years, natural aphid flights from the adjacent traps are sufficient to produce a uniform infection.

Symptom expression (dwarfing and discoloration) of tolerant and susceptible barley plants is usually sufficiently distinct to allow accurate classification. For barley, a visual rating system using a 0 to 4 scale was used (Schaller et al., 1963):

Type 0 Immune; no visible dwarfing or discoloration.
Type 1 Highly resistant; trace to slight discoloration, none to slight dwarfing; plants appeared thrifty and vigorous to maturity.
Type 2 Moderately resistant; moderate discoloration, limited dwarfing.
Type 3 Moderately susceptible; extensive discoloration; moderate dwarfing.
Type 4 Susceptible; severe dwarfing and discoloration; in some cases the plants were killed.

This scale was expanded, first to a 1 to 10 scale, and later as a 0 to 9 scale (Table 3) for use in wheat by Topcu (1975). We now use this system for oats as well. The more limited scale (0 to 4) serves quite well for barley because of the large difference in symptom expression between resistant and tolerant types. We prefer to retain a 0 score for wheat because it most often indicates escape from infection. Wheat shows less striking discoloration (yellow, red, and purple) than barley and effects of dwarfing and tiller reduction are more difficult to assess. Plants should be scored at several growth stages, including tillering, jointing, and at heading time.

In screening collections of cultivars it is desirable to replicate single-row plots because of variable expression in different parts of a test nursery. This is especially impor-

Table 3.

BYDV Visual Scoring System Used for Wheat.

Rating	Description
0	Disease free. Immune or escaped infection.
1	Trace amounts of yellowing at the tips of a few leaves; vigorous plant appearance.
2	Restricted yellowing of leaves; larger proportion of yellowed areas; relative to class 1, more leaves were discolored.
3	Moderate to low amount of yellowing, no sign of dwarfing or reduction in tillering.
4	Moderate to somewhat extensive yellowing; no dwarfing, moderate to good plant vigor.
5	More extensive yellowing, moderate to poor plant vigor; some dwarfing.
6	High level of yellowing, poor plant vigor, apparent dwarfing.
7	Severe yellowing, small spikes, moderate dwarfing, poor plant appearance.
8	Nearly complete yellowing of all the leaves, dwarfing; tillering apparently reduced (rosette appearance), reduced spike size with some sterility.
9	Marked dwarfing, complete yellowing, few or no spikes with considerble sterility; forced maturity or drying of the plant before normal maturity is reached.

tant for wheat because the most tolerant sources show considerable BYDV in some plantings. When the world collection of barley was screened (Schaller et al., 1963) one replicate of single row plots was sufficient because of the very high level of resistance that was found. All entries showing some indication of resistance were retested in subsequent years. We found 2 replicates of single row plots, with testing over several years to be adequate for wheat (Qualset et al., 1977).

When cultivars known to be quite homogeneous are being screened, it is possible to score plots for BYDV that are planted at normal seeding rates; however, segregating populations or heterogeneous cultivars might not be accurately scored at high plant density. In wheat and oats we have used 30 cm spacing between plants in single-row plots and scores applied to individual plants. This method appears quite satisfactory because plants escaping infection can be noted (0 score) (Topcu, 1975).

Since we were having difficulty in identifying sources of resistance in wheat, it seemed useful to attempt to establish yield losses caused by BYDV with known cultivars. Those cultivars least affected by BYDV could then be intercrossed and used in selection for higher tolerance. The systemic insecticide method mentioned earlier was used for this purpose. The results in Table 1 show that the wheat cultivars Anza and CI 13232, previously known to have some tolerance (Qualset et al., 1973), have only 20% improvement in yield when treated with the insecticide. As mentioned earlier, the resistant barley cultivars show almost no response to the insecticide. The 20% value for wheat seems reasonable as an expression of tolerance. Likewise, the wheat cultivars known to be highly susceptible (Ramona 50 and Oviachic 65) showed 40-50% yield improvement by the insecticide treatment, comparable to the susceptible barleys (Atlas 57 and California Mariout). Two cultivars, Inia 66R and Lerma Rojo 64, appear as tolerant as Anza on this basis. This was a rather surprising result, but both cultivars have shown very good performance records in California. Sonora 64 was more variable, and by these results, more susceptible to BYDV. It appears that this method will aid in the detection of tolerant cultivars.

Developing BYDV Resistant Barleys

More than 7000 barley entries from the U.S. Department of Agriculture World Collection were screened for reaction to BYDV at Davis, California (Qualset and Schaller, 1969; Schaller, Rasmusson and Qualset, 1963).

One hundred eighty nine of the entries had mean values of 2.00 or less, which is considered a tolerant reaction. All but six were introductions from Ethiopia; three were of hybrid origin from Ethiopian parentage; two were from Sudan (probably of Ethiopian origin) and one was from China. Although the mean reaction values form a continuous series from 0.50 to 2.00, different levels of resistance were suggested on the basis of severity and consistency of symptom expression and those with

lower mean values appear to be more desirable as parental material. Although differences in pathogenicity among isolates have been reported, a number of the Ethiopian entries found to be tolerant at Davis have given tolerant reactions when tested over a wide area and were probably exposed to different strains of the virus.

Genetic analyses of resistance to BYDV in 20 Ethiopian barleys (Catherall and Hayes, 1966; Damsteegt and Bruehl, 1964; Hayes et al., 1971, Rasmusson and Schaller, 1959; Schaller, Qualset, and Rutger, 1964) have shown that the same gene (Yd_2) conditioned resistance in all cultivars tested, although the possibility of closely linked genes or a series of alleles cannot be excluded. This gene is located on chromosome 3 (Schaller et al., 1964). Although apparently conditioned by the same gene (or locus), the level of tolerance between cultivars ranged from 0.83 to 1.60 and parental reaction ranges were observed among progenies of resistant x resistant crosses. Hayes et al. (1971) found that the expression of tolerance in the F_2 generation of tolerant x susceptible crosses varied among tolerant parents and the conditions under which they were tested. Tolerance was expressed as complete dominance in crosses with CI 3906-1, which possessed the highest level of tolerance, was incompletely dominant in crosses with parents of intermediate levels and, under some conditions, recessive in crosses with CI 1237, which had the lowest level. They also found a significant positive correlation between levels of tolerance expressed by the parents and progeny with growth rate, suggesting that environmental or genetic factors which delay heading diminish the expression of BYDV tolerance. Jones and Catherall (1970a) experienced difficulty in recovering late maturing segregates and suggested that the $\underline{Yd_2}$ gene operates by retarding virus multiplication, thus allowing the virus to reach higher concentrations in slower growing plants. This is not in complete agreement with our experience at Davis. Sutter barley which is 3 weeks later in maturity than CM 67, has tolerance levels as high or higher than the latter (Table 2).

In reviewing the results of wide-scale testing of the Ethiopian entries and subsequent genetic studies, it is apparent that, irrespective of demonstrated differences in pathogenicity of virus isolates, a number of those found to be tolerant at Davis, California would be satisfactory as parents in many areas of the world. Those with the lowest mean reaction values at Davis appear to provide the broadest coverage and transmit the highest level of tolerance to their progeny. Although only one gene has been identified in this group, the varying levels of tolerance could be attributed to closely linked genes, multiple allelic series, differences in genetic background and modifying genes, including those controlling growth rate.

The fact that differences in pathogenicity of virus isolates have been demonstrated and as only one major gene conditioning resistance in barley ($\underline{Yd}_2$) has been identified, further emphasizes the need for screening additional populations on a world-wide basis, followed by more detailed genetic analyses of the basis of resistance. World-wide testing would expose the populations to different strains and permit a more accurate cataloging of resistant types.

Developing BYDV Resistant Wheats

Several workers have screened large portions of the U.S. Department of Agriculture World Wheat collection for resistance to BYDV with rather disappointing results (see Qualset et al., 1973). At Davis, J. C. Williams began a search for resistance in the World Collection in 1961. From more than 5,000 entries screened he found CI 13232 (=Coker 55-9, a selection from Chancellor^2 x T. Hybrid) to have good tolerance. Others were identified as potentially useful, but subsequent tests proved them to be susceptible.

In 1969, the International Spring Wheat Yield Nursery was grown at two locations in California. At Isleton in the Sacramento-San Joaquin River Delta region the incidence of BYDV was high and it was obvious that the entry number 23, a CIMMYT variety entered by M. A. Khalifa of the Sudan, was much less affected than other entries in the test. This entry, (Lerma Rojo x Norin 10-Brevor) x Andes^3_e , performed very well in subsequent tests and was named Anza and released in 1971 (Qualset et al., 1973). It is widely adapted throughout the world and one can speculate that its tolerance to BYDV contributes to its good performance.

Recently we reported the results of five years of testing of the Ethiopian tetraploid wheats from the U.S.D.A. World Collection (Qualset et al., 1977). This study was based on the observation that Ethiopia was the only source of resistance to BYDV in barley. It was hoped that parallel results might be obtained with wheat. The results were not exceptionally promising, but 40 entries of out of the 584 tested had low scores over the 5-year period. CI 17610 had the lowest score and is worthy of trial in breeding programs.

Both Anza and CI 13232 have been shown to be usable parents in breeding for tolerance to BYDV (to be discussed below), but it is clear that additional sources of resistance should be identified. Three approaches are suggested: (i) Expand testing of breeding lines at several "hot spots" throughout the world. This should aid in identifiying selections with higher levels of tolerance derived from favorable crosses, such as those involving Anza; (ii) Expand testing of related wild and primitive cultivated species. In addition, several sets of alien addition and substitution lines are now available and should be routinely tested for resistance to BYDV and other diseases; (iii) Attempt to transfer $\underline{Yd}_2$ from barley to wheat. We have a program in progress in which it appears that we will be able to develop wheat lines with the barley chromosome 3 added (Jan et al. 1979). Experience obtained in Australia where Islam et al. (1977 and unpublished) have developed 6 of the 7 addition lines should be valuable in this attempt.

In 1973 we showed that F_1s of crosses with Anza showed dominance toward BYDV tolerance and that significant genetic variation for BYDV score was found in the F_3 generation (Qualset et al., 1973). Topcu (1975) did extensive studies with two crosses, Anza x Bluebird-2 and Anza X CA 63121, with CA 63121 being a selection from CI 13232 X Ramona 50. His results confirmed the earlier interesting result that a tolerant X tolerant cross generated more genetic variance than a tolerant X susceptible cross; however, it appeared that lines could be selected from either cross that would be better than the best parent. Topcu also showed that BYDV reaction was heritable by testing selections in the F_4 from F_3 progenies with high and low BYDV scores (Table 4). He used an early fall planting (October) and a late spring planting (March) to take advantage of BYDV transmission from fall and spring aphid flights. The F_4L lines from both crosses had significantly lower scores than the F_4H lines. The F_4L lines had, on the average, lower scores than the F_3 population in three of four cases in Table 4.

Even though the search for sources of resistance in wheat has been only moderately successful, it appears that significant advances can be made in developing highly tolerant cultivars by recurrent selection in populations derived from crosses involving the best tolerance now available. Obviously, Anza wheat should be considered as a parent for this purpose. Breeders must be prepared to save some materials with considerable BYDV symptoms for use as parents in new cycles of selection.

In California, derivatives from crosses involving Anza have shown promise for BYDV tolerance. Shasta, released in 1976 from the cross Inia 66 X Anza, apparently has tolerance about equal to Anza, and it was shown earlier (Table 1) that the other parent, Inia 66R (a selection from Inia 66) also has some tolerance based on the yield reduction study.

Table 4.

Effect of Selection in F_3 on BYDV in F_4 Progeny.

Hybrid and generation*		n	Date Planted	
			October	March
Anza x Bluebird-2	F_3	50	3.5	3.6
	F_4H	40	3.2	3.9
	F_4L	105	2.7	3.6
Anza x CA 63121	F_3	40	2.7	3.1
	F_4H	99	3.0	3.0
	F_4L	50	2.3	2.7
Anza		35	1.6	2.0
Bluebird-2		15	2.5	3.5
CA 63121		16	1.9	2.5

*F_4H and F_4L were progeny from F_3 lines with High and Low scores, respectively.

Literature Cited

Allen, T. C. Jr. 1957. Strains of the barley yellow dwarf virus. Phytopath. 57:481-490.

Arny, D. C. and H. Jedlinski. 1966. Resistance to the yellow dwarf virus in selected barley varieties. Plant Dis. Reptr. 50:380-381.

Bruehl, G. W. 1961. Barley yellow dwarf virus. Amer. Phytopath. Soc. Monogr. 1: 52 pp.

Bruehl, G. W. and H. V. Toko. 1957. Host range of two strains of the cereal yellow dwarf virus. Plant Dis. Reptr. 43:471-474.

Catherall, P. L. and J. D. Hayes. 1966. Assessment of varietal reaction and breeding for resistance to yellow dwarf virus in barley. Euphytica 15:39-51.

Close, R. C. 1970. Summary of trials for the control of barley yellow dwarf virus. N.Z. Wheat Rev. 11:66-69.

Damsteegt, V. D. and G. W. Bruehl. 1964. Inheritance of resistance in barley to barley yellow dwarf. Phytopath. 54: 219-224.

Doodson, J. K. and P. J. W. Saunders. 1970. Some effects of barley yellow dwarf virus on spring and winter cereals in field trials. Ann. Appl. Biol. 66:361-374.

Fitzgerald, P. J. and W. N. Stoner. 1967. Barley yellow dwarf studies in wheat (Triticum Aestivum L.) I. Yield and quality of hard red winter wheat infected with barley yellow dwarf virus. Crop Sci. 7:337-341.

Gill, C. C. 1967. Susceptibility of common and durum spring wheats to barley yellow dwarf virus. Can. J. Plant Sci. 47:571-576.

Gill, C. C. and K. W. Buchannon. 1972. Reaction of barley hybrids from crosses with CI 5791 to four isolates of barley yellow dwarf virus. Can. J. Plant Sci. 52:305-309.

Hayes, J. D., P. L. Catherall and A. T. Jones. 1971. Problems encountered in developing BYDV tolerant European cultivars of barley. Barley Genetics II:493-499 (Proceeding of the Second International Barley Genetics Symposium; Washington State University Press.)

Islam, A. K. M. R., K. W. Shepherd, and D. H. B. Sparrow. 1977. Wheat-barley hybrids and addition lines. Proc. SABRAO Congress, Canberra, Australia 2a:9-13.

Jan, C. C., J. Dvorak, C. O. Qualset, and C. W. Schaller. 1979. Hybridization between Triticum aestivum L. and Hordeum vulgare L. American Soc. Agronomy. Agronomy Abstracts. p. 64.

Jones, A. T. and P. L. Catherall. 1970a. The relationship between growth rate and the expression of tolerance to barley yellow dwarf virus in barley. Ann. Appl. Biol. 65:137-145.

Jones, A. and P. L. Catherall. 1970b. The effect of different virus isolates on the expression of tolerance to barley yellow dwarf virus in barley. Ann. Appl. Biol. 65:147-152.

Murphy, H. C. 1959. The epidemic of barley yellow dwarf on oats in 1959. Plant Disease Reptr. Suppl. 262.

Oswald, J. W., and B. R. Houston. 1953. The yellow dwarf virus disease of cereal crops. Phytopath. 43:128-136.

Price, R. D. and L. L. Stubbs. 1963. An investigation of the barley yellow dwarf virus as a primary or associated cause of premature ripening or "dead heads" in wheat. Aust. J. Agric. Res. 14:154-164.

Qualset, C. O. and C. W. Schaller. 1969. Additional sources of resistance to the barley yellow dwarf virus in barley. Crop Sci. 9:104-105.

Qualset, C. O., P. E. McGuire, H. E. Vogt, and M. A. Topcu. 1977. Ethiopia as a source of resistance to the barley yellow dwarf virus in tetraploid wheat. Crop Sci. 17:527-529.

Qualset, C. O., J. C. Williams, M. A. Topcu, and H. E. Vogt. 1973. The barley yellow-dwarf virus in wheat: Importance, sources of resistance, and heritability. Proc. 4th Inst. Wheat Genetics Symp. Missouri Agric. Expt. Sta., Columbia, Mo. p. 465-470.

Qualset, C. O., J. D. Prato, J. A. Rupert, H. E. Vogt, M. A. Khalifa, W. F. Lehman, and W. H. Isom. 1973. Anza - A new high-yielding short-statured wheat variety. Calif. Agric. 27(2):14-15.

Rasmusson, D. C. and C. W. Schaller. 1959. The inheritance of resistance in barley to the barley yellow dwarf virus. Agron. J. 51:661-664.

Rochow, W. F. 1959. Transmission of strains of barley yellow dwarf virus by two aphid species. Phytopath. 49:744-748.

Rochow, W. F. 1961. The barley yellow dwarf virus disease of small grains. Adv. Agron. 13:217-248.

Rochow, W. F. 1972. The role of mixed infections in the transmission of plant viruses by aphids. Ann. Rev. Plant Path. 10:101-124.

Schaller, C. W., and C. O. Qualset. 1978. Progress and problems in breeding for resistance to the barley yellow dwarf virus in barley and wheat. Proc. Wheat and Barley Production Workshop. CIMMYT-CIAA-INIAP Quito, Ecuador (in press).

Schaller, C. W., C. O. Qualset, and J. N. Rutger. 1964. Inheritance and linkage of the $\underline{Yd_2}$ gene conditioning resistance to the barley yellow dwarf virus disease in barley. Crop Sci. 4:544-548.

Schaller, C. W., D. C. Rasmusson, and C. O. Qualset. 1963. Sources of resistance to the yellow dwarf virus in barley. Crop Sci. 3:342-344.

Slykhuis, J. T. 1967. Virus diseases of cereals. Rev. Appl. Mycol. 46:401-429.

Smith, H. C. 1963. Aphid species in relation to the transmission of barley yellow dwarf virus in Canada. New Zealand Agric. Res. 6:1-12.

Smith, H. C. 1967. The effect of aphid numbers and stage of plant growth in determining tolerance to barley yellow dwarf virus in cereals. New Zealand J. Agric. Res. 10:445-446.

Stanley, W. W. and C. O. Qualset. 1968. Effect of a systemic insecticide on forage and grain production of wheat, barley, oat, and rye varieties. Agron. J. 60:306-308.

Toko, H. W., and C. W. Bruehl. 1959. Some host and vector relationships of strains of the barley yellow-dwarf virus. Phytopath. 49:343-347.

Topcu, M. A. 1975. The inheritance of resistance to the barley yellow dwarf virus in wheat (Triticum aestivum L.). Ph.D. Dissertation Univ. Calif., Davis, Ca. (Diss. Abst. 36:3226-B).

Watson, M. A., and T. E. Mulligan. 1960. Comparison of two barley yellow dwarf viruses in glasshouse and field experiments. Ann. Appl. Biol. 48:559-574.

Wiese, M. V. 1977. Compendium of wheat diseases. Amer. Phytopath. Soc., St. Paul, Minn. U.S.A.

DISEASE REACTION TO SEPTORIA NODORUM OF F_1 WHEAT CROSSES

L. R. Nelson and C. E. Gates
United States

Abstract

Results from a diallel analysis involving six wheat parents and all possible F_1 plants (including reciprocals) for disease reaction to Septoria nodorum (Berk.) Berk. indicated significant effects of specific and general combining ability as well as reciprocal effects. Data in this report will provide additional information on inheritance of host plant resistance to S. nodorum. In addition, we hope to confirm the significance of reciprocal effects and separate reciprocal effects into maternal versus reciprocal differences. These studies are being conducted under greenhouse and humidity chamber conditions. Results should provide information for plant breeders to aid them in selecting the breeding methods most effective in developing resistance to S. nodorum.

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Summary

Five wheat (Triticum aestivum L. em. Thell) parents and all possible F_1 crosses (reciprocals included) making up a diallel series were inoculated and tested for glume blotch (Septoria nodorum (Berk.) Berk) during the heading stage. Significant differences were found for entries, line effects, heterosis, and average heterosis. No differences were noted for specific heterosis or for cytoplasmic inheritance. Cultivars with the most resistant line estimates for genetic constants were 'Oasis' and 'Blueboy II'. More susceptible cultivars were 'McNair 1813' and 'Holley'. 'IAS-20' had an intermediate genetic constant value. We found that F_1 crosses tended to be more resistant than the parents making up the crosses which indicated heterosis had a positive effect on resistance to S. nodorum.

Introduction

Glume blotch caused by Leptosphaeria nodorum Muller, imperfect stage, Septoria nodorum (Berk.) Berk caused significant yield reductions in wheat (Triticum aestivum L. em Thell) in

Texas A&M University Agricultural Research and Extension Center at Overton and College Station.

Texas and much of the Southern U.S. each year. In years with above average rainfall during the heading stages severe epiphytotic conditions may result (9, 10). Wheat germplasm has been identified and reported which has some resistance to Septoria nodorum (6, 7, 9). Under different environmental conditions some purportedly resistant lines do not always express resistance. When subjected to ideal Septoria conditions (such as are found in a humidity chamber) all cultivars may become diseased to some degree.

Various techniques have been employed to isolate and culture S. nodorum under laboratory conditions (5, 11). Inoculation procedures can be employed to test host plant resistance under controlled conditions. Few genetic studies on resistance of wheat to S. nodorum have been reported, however, in an earlier study, the senior author (8) noted significance for general combining ability (GCA) and for specific combining ability (SCA). Cultivars 'Oasis' and 'Blueboy II' had the largest GCA effects for resistance while McNair 1813 and IAS-20 had GCA effects for susceptibility. The objective of this experiment was to study the inheritance of resistance to S. nodorum, and to gain a better understanding of the nature of "gene action for resistance". Specifically, it was hoped to determine if heterosis or cytoplasmic inheritance played a role in host plant resistance to Septoria nodorum.

Materials and Methods

This study was conducted in the greenhouse during the winter of 1979-80. The experiment involved a diallel cross with reciprocals and parents (p^2=25). Cultivars classified as resistant making up the diallel series were 'Oasis' and 'Blueboy II' and 'IAS-20'. Susceptible cultivars were 'McNair 1813' and 'Holley'. Germinating seed were cold treated for 48 days to vernalize all seedlings. Three planting dates at 2-week intervals were used in order to select plants at the same stage of growth for treatment. Two vernalized seedlings were transplanted into each pot (13 cm tall by 17 cm diameter) and allowed to head. At the milk stage, a complete set of plants (25 genotypes) was placed in a humidity chamber. Plants were inoculated with a suspension of S. nodorum and held in the chamber for 72 hours. Two chambers were operated at the same time, thus two replications were run concurrently. Spore counts varied with run from a low of 6.3×10^6 spores per ml for replications 9 and 10 to a high of 1.65×10^7/ml for replications 1 and 2. When plants from the first two replications were removed from the chambers, plants from the third and fourth replications were placed in the chamber and inoculated. This procedure was repeated until 10 replications had been run. The humidity chambers were placed on a greenhouse bench and were directly under a bank of fluorescent lights which were set for a 16 hr day. A cool mist blower operated throughout the experiment. The temperature in the greenhouse was maintained between 20 and 25 C. Upon removal from the chamber, the plants were held in the greenhouse for 14 days and disease severity ratings recorded. Disease ratings were taken on a scale from 0 to 9 where 0 equalled no damage, and 9 equalled plants killed by the

disease. The mean rating for two plants in each pot was used for statistical analysis. The S. nodorum isolate was obtained from Dr. B. M. Cunfer at the Georgia Experiment Station, Experiment, Georgia. Inoculum was grown on yeast-malt agar for 2 to 3 weeks and washed off the agar with distilled water. Inoculum buildup on the agar was greatly increased by placing two or three sterilized green wheat leaves on the agar when the inoculum was transferred to new agar. Liquid ivory soap was used as a wetting agent. All plants were sprayed to run off with a hand held sprayer.

Data were anlyzed for a diallel series (with plants and reciprocals included) similarly to the Gardner and Eberhart procedure (2, 3) which has some advantages over the procedure outlined by Griffing (4). Maternal and reciprocal effects were partitioned as outlined by Crosbie, Mock and Pearce (1).

Results and Discussion

Disease ratings ranged from 1 to 9 with a mean rating of 4.3 for the entire test. In the analysis (Table 1), significance is observed for replications, entries, line effects, heterosis, average heterosis and line heterosis.

Table 1
Analysis of variance of five cultivars and their 20 F_1 crosses (including reciprocals).

Source	Degrees of freedom	Mean squares
Total	249	
Replications	9	2.327*
Entries	24	8.423**
Line effects	4	1.090**
Heterosis	12	1.485**
Av. Heterosis	1	12.638**
Line Heterosis	4	0.266*
Specific heterosis	4	0.230
Maternal effects	4	0.130
Reciprocal difference	6	0.080
Error	216	0.106

*, **Indicates significance at the 0.05 and 0.01 probability levels respectively.

Maternal or reciprocal mean squares were not significant, therefore, data for reciprocal crosses were averaged and are shown in table 2.

Table 2
Mean *Septoria nodorum* disease ratings for parents and crosses.

	Holley	Blueboy II	Oasis	McNair 1813	IAS-20
Holley	5.7+	3.5	4.1	4.3	3.7
Blueboy II		5.0	3.1	4.1	3.6
Oasis			4.5	3.7	3.5
McNair 1813				7.1	3.5
IAS-20					5.3

+Underlined means are for cultivars.

Of the crosses, Blueboy II x Oasis had the lowest disease rating of 3.1, while the cross Holley x McNair 1813 had the highest disease rating of 4.3. McNair 1813 had the highest ratings of the cultivars with 7.1. Significant differences for replications may have been due to heavier spore concentrations on some replications or differences in humidity chambers (or mist blowers). Differences for line effects indicate general differences for resistance to Septoria of the progeny of the parents (similar to general combining ability described by Griffing (4)). Estimates of genetic constants for the five cultivars (Table 3, V_1 through V_5) indicate that superior lines were Oasis and Blueboy II. Recall that a negative value is superior since resistant crosses have disease ratings below average.

Table 3.
Estimates of genetic constants from data in table 1.

Cultivar or cross		Genetic constant	Standard error
μ^v	Variety means	5.49	± .15
V_1	Holley	+0.16	± .29
V_2	Blueboy	-0.49	± .29
V_3	Oasis	-1.04	± .29
V_4	McNair 1813	+1.61	± .29
V_5	IAS-20	-0.24	± .29
$\bar{h}$	Average heterosis	-1.778	± .163
h_1	Holley	+0.178	± .188
h_2	Blueboy	+0.053	± .188
h_3	Oasis	+0.353	± .188
h_4	McNair 1813	-0.651	± .249
h_5	IAS-20	+0.067	± .249
S_{12}	Holley x Blueboy II	-0.254	± .163
S_{13}	Holley x Oasis	+0.296	± .163
S_{14}	Holley x McNair 1813	+0.200	± .266
S_{15}	Holley x IAS-20	-0.242	± .266
S_{23}	Blueboy II x Oasis	-0.329	± .163
S_{24}	Blueboy II x McNair 1813	+0.450	± .266
S_{25}	Blueboy II x IAS-20	+0.133	± .266
S_{34}	Oasis x McNair 1813	-0.362	± .488
S_{35}	Oasis x IAS-20	+0.396	± .410
S_{45}	McNair 1813 x IAS-20	-0.288	± .163

Heterosis was significant, which indicated F_1 crosses will react differently to Septoria than cultivars due to heterosis. The average heterosis ($\bar{h}$ in Table 3) is -1.778. This indicates that F_1 crosses tended to have a lower disease rating than did the parent cultivars. Note that in Table 2, parents did have rather high mean disease ratings compared to the crosses. Even Oasis had a mean rating of 4.5 while all crosses involving Oasis had a mean rating of only 3.6. Significant line heterosis indicates some parents (cultivars) have significantly different degrees of heterosis for resistance to Septoria. Estimates of genetic constants for line heterosis (Table 3, h_1 through h_5) are presented. The negative value of -0.651 for McNair 1813 indicates that crosses involving this line had more disease resistance than was expected and the heterosis may have been the cause for this resistance. Specific heterosis, maternal or reciprocal (cytoplasmic inheritance) mean squares were not significant, however, genetic constants are shown for specific genetic constants (Table 3, S_{12} through S_{45}).

Our results from this study are similar to results of a previous study (8). In both studies, the cultivars Oasis and Blueboy II produced F_1 crosses which had resistant genetic effects for resistance to S. nodorum. McNair 1813 and Holley produced F_1 crosses which were susceptible to S. nodorum. Crosses involving IAS-20 were more resistant to Septoria in this study than the previous experiment. In the previous study, some evidence for reciprocal differences was noted, however, results from this study indicate no effect due to either reciprocal or maternal differences. Our results indicate that heterosis affects disease severity of F_1 crosses, and with the cultivars involved in this study tended to increase resistance over the parents.

Additional studies are needed to determine whether dominance and epistasis are affecting the inheritance of host plant resistance to S. nodorum.

References

1. Crosbie, T. M., J. J. Mock and R. B. Pearce. 1978. Inheritance of photosynthesis in a diallel among eight maize inbred lines from Iowa stiff stalk synthetic. Euphytica 27:657-664.

2. Eberhart, S. A. and C. O. Gardner. 1966. A General Model for Genetic Effects. Biometrics 22:864-881.

3. Gardner, C. O. and S. A. Eberhart. 1968. Analysis and interpretation of the variety cross diallel and related population. Biometrics 22:439-452.

4. Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems. Australian J. Biol. Sci. 9:463-493.

5. Krupinsky, J. M. 1976. Techniques for screening wheat for Septoria resistance. In. Proceedings of the Septoria Diseases of Wheat Workshop. Univ. of Georgia Agric. Exp. Sta. Special Pub. No. 4 pp. 28-33.

6. Krupinsky, J. M., J. A. Schillinger and A. L. Scharen. 1972. Resistance in wheats to *Septoria nodorum*. Crop Sci. 12: 528:531.

7. Morey, D. D. 1976. Overview of genetic resistance to *Septoria nodorum*. In. Proceedings of the Septoria Diseases of Wheat Workshop. Univ. of Georgia Agric. Exp. Sta. Special Pub. No. 4 pp. 61-63.

8. Nelson, L. R. 1980. Inheritance of resistance to *Septoria nodorum* in wheat. Crop Sci. 20: (accepted for publication).

9. Nelson, L. R., D. D. Morey and A. R. Bowne. 1974. Wheat cultivar responses to severe glume blotch in Georgia. Plant Dis. Reptr. 58: 21-23.

10. Nelson, L. R., M. R. Holmes and B. M. Cunfer. 1976. Multiple regression accounting for wheat yield reduction by *Septoria nodorum* and other pathogens. Phytopathology 66: 1375-1379.

UTILIZING THE COEVOLUTION OF WHEAT AND HESSIAN FLY BIOTYPES AS A TOOL FOR DEVELOPING RESISTANT WHEAT CULTIVARS IN THE RAINFED AREAS OF THE UNITED STATES

R. L. Gallun and F. L. Patterson
United States

Abstract

This paper will stress the cooperative research involved in studying the genetics of wheat and Hessian fly and in utilizing the gene for gene concept to develop wheat cultivars resistant to evolving Hessian fly biotypes. Both laboratory and field experiments will be used to exemplify this interdisciplinary effort to protect the wheat crop from an insect pest.

Wheat cultivars that are resistant to the Hessian fly, Mayetiola destructor (Say), and the occurrence of biotypes that can overcome these resistant wheats reflect the co-evolution of the insect and the wheat plant that has taken place in the United States during the past 50 years. By utilizing this co-evolutionary process in a genetics program we have been able to develop wheats that are resistant to the constantly changing insect.

The adult flies emerge from infested wheat plants and then mate and oviposit on wheat seedlings. The small red larvae, approximately 1/2 mm in length, crawl down the leaf, between the leaf sheaths to the base of the plant where they begin to feed. Here the larvae survive or die depending upon the plant's reaction to the insect. If the plant is resistant, the larvae die and the plant continues to grow normally. If the plant is susceptible, the larvae survive and the plant becomes stunted. A susceptible plant is dark green in color and the larvae develop to maturity.

Prior to the discovery of wheats that showed resistance to field populations of Hessian fly, very little was known about the genetics of resistance to the insect pest or about the occurrence of biotypes. It was in 1931 when the first biotype was described (Painter et. al., 1931). This biotype is what we now call the Great Plains biotype because of its occurrence in the Great Plains states of Kansas and Nebraska. Painter described this biotype as being different from that found in Indiana because wheat varieties that were attacked by the Indiana biotype were not attacked by the Great Plains biotype. In 1935 the cytology of Hessian fly was studied (Metcalfe, 1935) by using the Great Plains biotype. Metcalfe's paper described the elimination of paternally derived chromosomes in two unequal divisions during spermatogenesis, a phenomenon that later was to plan an important role in Hessian fly genetics. (Oogenesis is normal). However, during the 1930's no

Purdue University and USDA/SEA-AR

wheat cultivars were released that were developed for resistance to Hessian fly although wheat breeders were now including resistance in their breeding materials.

During the 1940's a few California wheats were released that had resistance to California fly and the genetic factors H_1 and H_2 in Dawson wheat were described as conferring resistance to the Great Plains biotype in California (Noble and Suneson, 1943). A few wheat varieties utilizing these genes for resistance were released in California and were reported to have eliminated Hessian flies from the area. In 1946 the H_3 gene for resistance was described by wheat breeders in Indiana (Caldwell et. al., 1946). This gene conferred resistance to the Great Plains biotype and to biotype A, a new biotype that had evolved on those wheats in the eastern soft wheat region that had resistance from Seneca wheat. Biotypes A and B were subsequently described as being in Indiana (Cartwright and Noble, 1947). Biotype B can survive on wheat having the H_3 gene whereas the Great Plains biotype and biotype A cannot. During the 1940's wheats having the H_3 gene for resistance were being developed in Indiana and a few other states in the eastern soft wheat region. However, a biotype capable of attacking wheats having the H_3 gene for resistance had been identified even before the release of these wheats.

During the 1950's the H_5 gene conferring resistance to biotypes A and B was identified and described (Shands and Cartwright, 1953) as was the H_6 gene derived from a durum wheat (Allen et. al., 1959). Both the H_6 gene and the H_5 gene provided resistance to biotypes A and B. In 1955 a wheat variety called Dual was released in Indiana. This variety was the first soft red winter wheat bred for Hessian fly resistance that was released in the eastern soft wheat region. Three other soft red wheats having the H_3 gene were also released during this decade. By the end of the 1950's approximately 40 percent of the Indiana wheat acreage was planted to resistant cultivars.

In the 1960's ten additional soft winter wheat cultivars were released that had the H_3 gene for resistance and these wheats were grown on much of the wheat acreage. By 1970 more than 90% of the wheat acreage in Indiana was planted to wheat cultivars having resistance to Hessian fly. Since most of these varieties had the H_3 gene, biotype B populations replaced biotype A. Also during the 1960's two wheats were released in Indiana that had the H_6 gene for resistance to populations of biotypes A & B, but because of agronomic type they were not accepted by farmers. However, they had excellent fly resistance and were used as parents in crosses for further breeding of resistant wheats.

In 1961 two new biotypes, C & D, were described (Gallun et. al., 1961). Biotype C is able to attack wheats having the H_6 gene for resistance but not wheats having the H_3 gene. Biotype D, developed in the laboratory from matings between biotypes B & C, can attack wheats having either or both of the H_3 and H_6 genes for

resistance. Populations of these biotypes were used to evaluate wheats for new sources of resistance.

In 1966 a durum wheat, PI 94587 was discovered to have 4 or more dominant genes for resistance to biotype A (Caldwell et. al., 1966). In 1969 another new biotype, biotype E was discovered in southeastern United States (Hatchett, 1969). This biotype can survive on wheats having the H_3 gene for resistance; however, it cannot survive on wheats having the Seneca resistance, later described as having the H_7 nd H_8 genes (Patterson and Gallun, 1973). This information promoted the use of Seneca in breeding programs to protect the wheat in southeastern United States from biotype E. Also, Hatchett and Gallun in 1967 reported that the genes conferring avirulence of a specific biotype to a wheat plant by a specific biotype were dominant to genes conferring virulence of a different biotype to the same wheat plant. This knowledge led to the development of a model for genetic control of Hessian fly biotypes that can attack resistant wheat varieties (Hatchett and Gallun, 1967). If such populations of Indiana Hessian flies are inundated with a large number of Great Plains biotype, which has dominant genes for avirulence at every loci, the majority of progenies that result from the matings cannot survive on Indiana wheats resistant to the Great Plains biotype.

During the 1970's our genetics research increased. Hatchett and Gallun (1970) showed that non-allelism for virulence occurred with biotypes A and E. Wootiprecha (1970) developed biotypes F and G by controlled breeding experiments and Foster and Gallun (1972) demonstrated that the model for genetic control worked in the field. Also we identified the wheat variety Knox 62 as having the H_6 gene derived from durum PI 94587 by using biotypes A and B, located this gene on chromosome 5A by monosomic analysis (Gallun and Patterson, 1977), showed that the H_3 factor was linked with the H_6 factor (Patterson and Gallun, 1977), and identified the independent duplicate partially dominant factors H_7 and H_8 in Seneca wheats that confer resistance to biotype E (Patterson and Gallun, 1973). Carlson et. al. (1978) discovered new genes for resistance to all known biotypes in Triticum turgidum and these genes were transferred to a common wheat named Elva. Other genetic research with the Hessian fly showed the genes conferring virulences of biotypes B and C were located on separate chromosomes and that some of the recombinant maternally derived chromatin matter was eliminated in spermatogenesis along with the derived centromere and accompanying chromatin (Gallun, 1978). Biotype L, a new biotype, was also described (Sosa, 1978). This biotype can live in wheats having either or all of the H_1, H_2, H_3, H_5, H_6, H_7, and H_8 genes for resistance. However, it cannot survive on wheats having resistance derived from Elva. In the 1970's nine wheat cultivars having Hessian fly resistance were released in the eastern soft wheat region. Five had the H_5 gene plus the H_3 gene for resistance, and four had only the H_3 gene. One variety named Downy, because of its pubescent leaf characteristic, has resistance

to the cereal leaf beetle, Oulema melanopus (L.), in addition to having the H_3 and H_5 genes for resistance to Hessian fly. By the end of the 1970's more than 80% of the wheats grown in the eastern United States had Hessian fly resistance.

During the 1980's the program of genetics research in both the wheat plant and the Hessian fly is being continued. Biotype J has already been discovered (Sosa, 1980, unpublished). It is similar to biotype L only in that it cannot survive on wheats having the H_6 gene for resistance. Gene H_9 (from Elva) which has resistance to all known biotypes, has been identified and the H_3, H_6, and H_9 genes have been shown to be located on chromosome 5A, and the H_3 and H_5 genes are now known to be inherited independently of each other (Stebbins et. al., 1980).

So this is the story we tell of the co-evolution of resistant wheat and Hessian fly biotypes during the last 50 years. Results of the research have "borne fruit". In 1979 the National Wheat Survey showed that approximately 20 million acres (8 million hectares) in the United States are planted to Hessian fly resistant cultivars. In the eastern soft wheat region where more than 80 percent of the wheat acreage is grown to resistant cultivars, Hessian fly populations have dropped well below the economic threshold level for significant loss in yield. We are still searching for new sources of resistance made possible by the development of new biotypes and will incorporate these sources into our wheat breeding program. By continuing our genetics research program we hope to continue producing Hessian fly resistant wheats until we run out of genes for resistance in wheat or genes for virulence in the Hessian fly. We hope it will be the Hessian fly that goes.

Literature Cited

Allan, R. E., E. G. Heyne, E. T. Jones, and C. D. Johnston. 1959. Genetic analyses of ten sources of Hessian fly resistance, their interrelationships and association with leaf rust reaction in wheat. Kans. Agric. Exp. Stn. Tech. Bull. 104. 51 pp.

Caldwell, R. H., W. B. Cartwright, and L. E. Compton. 1946. Inheritance of Hessian fly resistance derived from W 38 and durum PI 94587. J. Am. Soc. Agron. 38:398-409.

Caldwell, R. M., R. L. Gallun, and L. E. Compton. 1966. Genetics and expression of resistance to Hessian fly, Phytophaga destructor (Say). Proc. 2nd Int. Wheat Genet. Symp. Hereditas Suppl. 2:462-463.

Carlson, S. K., F. L. Patterson, and R. L. Gallun. 1978. Inheritance of resistance to Hessian fly derived from Triticum turgidum L. Crop Sci. 18:1011-1014.

Cartwright, W. B. and W. B. Noble. 1947. Studies on biological races of the Hessian fly. J. Agric. Res. 15(4):147-153.

Foster, J. E. and R. L. Gallun. 1972. Populations of the eastern races of the Hessian fly controlled by release of the dominant avirulent Great Plains race. Ann. Entomol. Soc. Am. 65:740-744.

Gallun, R. L. 1978. Genetics of biotypes B and C of the Hessian fly. Ann. Entomol. Soc. Am. 71:481-486.

Gallun, R. L. and J. H. Hatchett. 1969. Genetic evidence of elimination of chromosomes in the Hessian fly. Ann. Entomol. Soc. Am. 62:1095-1101.

Gallun, R. L. and F. L. Patterson. 1977. Monosomic analysis of wheat for resistance to Hessian fly. J. Hered. 68:223-226.

Gallun, R. L., H. O. Deay, and W. B. Cartwright. 1961. Four races of Hessian fly selected and developed from an Indiana population. Purdue Univ. Agric. Exp. Stn. Res. Bull. 732. 7 pp.

Hatchett, J. H. 1969. Race E, sixth race of Hessian fly, Mayetiola destructor (Say), discovered in Georgia wheat fields. Ann. Entomol. Soc. Am. 62:677-678.

Hatchett, J. H. and R. L. Gallun. 1967. Genetic control of the Hessian fly. Proc. NC Br. Entomol. Soc. Am. 22:100-101.

Hatchett, J. H. and R. L. Gallun. 1970. Genetics of the ability of the Hessian fly, Mayetiola destructor, to survive on wheats having different genes for resistance. Ann. Entomol. Soc. Am. 63:1400-1407.

Metcalfe, M. E. 1935. The germ cell cycle in Photophaga destructor (Say). Qt. J. Microsc. Sci. 4:585-606.

Noble, W. B. and C. A. Suneson. 1943. Differentiation of the two genetic factors in wheat for resistance to the Hessian fly. U.S. Dept. of Agric. Tech. Bull. 1004. 4 pp.

Painter, R. H., S. C. Salmon, and J. H. Parker. 1931. Resistance of varieties of winter wheat to Hessian fly, Phytophaga destructor (Say). Kans. Agric. Exp. Stn. Tech. Bull. 27:1-58.

Patterson, F. L. and R. L. Gallun. 1973. Inheritance of resistance of Seneca wheat to race E of Hessian fly. Proc. 4th Int. Wheat Genetics Symp. Mo. Agric. Exp. Stn. p. 445-449.

Paterson, F. L. and R. L. Gallun. 1977. Linkage in wheat of the H_3 and H_6 genetic factors for resistance to Hessian fly. J. Hered. 68:293-296.

Shands, R. G. and W. B. Cartwright. 1953. A fifth gene conditioning Hessian fly response in common wheat. J. Am. Soc. Agron. 45(7):302-307.

Sosa, O. Jr. 1978. Biotype L, ninth biotype of the Hessian fly. J. Econ. Entomol. 71:458-460.

Stebbins, N. B., F. L. Patterson, and R. L. Gallun. 1980. Interrelationships among wheat genes for resistance to Hessian fly. Crop Sci. 20:177-180.

Wootiprecha, S. 1971. Studies of genetic synthesis of new races of Hessian fly, Mayetiola destructor (Say). Ph.D. thesis, Purdue University. 187 pp.

COMMERCIAL CONTROL OF SPECKLED LEAF BLOTCH (*MYCOSPHAERELLA GRAMINICOLA* IMPERFECT STATE *SEPTORIA TRITICI*) OF WHEAT USING FUNGICIDES

F. R. Sanderson and R. E. Gaunt
New Zealand

Abstract

First signs of infection of speckled leaf blotch (*Mycosphaerella graminicola* - *Septoria tritici*) in New Zealand occur on seedlings at the 4-5 leaf stage. This early seedling infection has a greater potential effect on yield than does infection on the flag leaf. Infection is initiated by wind blown ascospores. Spore showers of which cease by the time the wheat has reached the 5-6 leaf stage. An application of fungicides at the 4-5 leaf stage has, therefore, a greater potential for controlling speckled leaf blotch and of preventing a yield loss than the universally accepted recommendation of spraying to protect the flag leaf.

Summary

There are two periods when infection of speckled leaf blotch (*Mycosphaerella graminicola*) has a marked effect on grain yield. The first and most important in the New Zealand situation, coincides with spikelet formation at growth stages 23 - 25. The result is a suppression of both seedling vigour and grain number. The second coincides with grain filling and is measured by reduced grain weight.

A single spray, after ascospore showers have ceased, yet before infection builds up just prior to spikelet formation, is suggested as an acceptable control strategy for this disease.

Introduction

During the 1970's there was an increasing awareness of the 'Septoria' diseases of wheat, to the point where they are now considered among the most consistently destructive pathogen in the majority of the wheat growing areas of the world.

Attention was first drawn to speckled leaf blotch (*Mycosphaerella graminicola*) in New Zealand by Cunningham who suggested that the failure of many commercial wheat crops to reach their expected potential yield during the mid-1950's was due to this disease. The first trial, in 1963, to assess the losses caused by speckled leaf blotch gave an increase in yield of 10% following only partial control of the disease on the flag leaf.

Crop Science Division, D.S.I.R., Lincoln, and
Department of Agricultural Microbiology, Lincoln College, Canterbury.

Since 1971, annual trials have been conducted at Lincoln, New Zealand to study the epidemiology and yield losses following infection by M. graminicola. The results of nine trials over the last five years have been to increase yields from 4.25 tonnes/ha to 5.11 tonnes/ha, representing a mean increase of just over 20%.

Symptoms

In New Zealand the first symptoms of speckled leaf blotch occur from late winter onwards when the seedlings have between 4-5 leaves and 2-5 tillers (Decimal scale 23-25; Feekes 3). Initially they are dark-green water soaked areas, often with associated yellowing, on the lowest or first true leaf of the seedling. Lesions spread rapidly to form light-brown irregular patches, which soon take on a speckled appearance as the small black pyenidia develop. Associated with the leaf lesions are extensive areas of yellowing and tip die-back which is generally confused with leaf senescence. It is for this reason that, when assessing sprayed vs.unsprayed plots, we record green leaf area, not area infected as per the standard diagram keys.

Aetiology

Initial infection of seedlings is by wind-borne ascospores produced on the old dead leaves of stubble remaining from the previous harvest, (Sanderson and Hampton, 1978). The most convincing argument for ascospore spread is the eveness of infection in seedling crops independent of the previous cropping history ie. whether the previous crop was either wheat or a break crop. Ascospore showers are dispersed long distances and are associated with periods of damp weather during the winter months. These ascospore showers become less frequent as the winter progresses. It appears from the work of J. S. Brown at the Victorian Wheat Research Institiute, Horsham, that a parallel situation occurs there under the different climatic conditions of Australia (J. S. Brown and R. E. Paddick 1978, J. S. Brown, pers. comm.).

Once infection is established within the crop, subsequent spread is by pycnospores produced in the fruiting bodies of the leaf lesions. These spores, unlike the ascospores, are primarily water-borne and travel only short distances within the crop during periods of rain.

Disease Loss

As the overall importance of a disease within a crop is measured in terms of yield loss, it is essential to consider disease in relation to the many components of yield. ie, the number of plants which become established, the number of tillers which mature, the number of florets which set seed, and the individual grain weight of seed harvested. Each of these components is set and subsequently modified at varying times during the life of the wheat plant. The overall effect of the disease should therefore be considered in relation to those growth stages associated with the different phases of the reproductive cycle of the plant.

Following the appearance of the first symptoms during late winter, there are two distinct periods when epidemics of speckled leaf blotch can have a marked effect on crop yield. The first - and we believe the most important - builds up remarkably rapidly, and coincides with spikelet initiation (Figure 1). Yield loss through early infection is,therefore, a result of reduced grain number (Table 1). There are also indications that early infection reduces seedling vigour for which, contrary to general belief, plants do not readily compensate.

The second infection period is very dependent on weather conditions, especially rain, during the later part of the growing season. The severity of this epidemic will determine the extent to which individual grain weight will be reduced. On a few occasions in New Zealand the epidemic has been sufficiently well advanced at flowering to have also an effect on grain number (Table 1).

Table 1. Percent loss of yield due to Mycosphaerella graminicola.

	1975-76		1976-77		
Location	1	2*	3	4	5
Loss due to early infection					
(Grain no.)	8.4	0	16.3	8.7	6.9
Loss due to late infection					
(Grain no.)	0	0	3.2	8.4	4.8
(Grain weight)	5.4	3.2	20.6	11.6	8.3
Total loss	13.8	3.2	40.1	28.7	20

* The trial at Location 2 was sprayed during October, too late to control the early epidemic.

Control

Under the normal commercial situation in New Zealand, a single spray of benomyl at 0.25kgai/ha, toward the end of winter, after ascospore showers have ceased, yet before symptoms develop (Figure 1) appears from last season's trials, and from observations and spore counts made from commercial crops sprayed during early spring, to be entirely adequate to control speckled leaf blotch.

If spore production and, hence, the epidemic is suppressed during late winter while the seedling wheat is at growth stage 23-25 (Feekes 3) then there will be no residual infection on the old dead leaves at the base of the plant to initiate the second infection cycle when the plants are reaching maturity.

References

Brown, J.S. and R.C. Paddick, 1978. The importance of speckled leaf blotch of wheat in Victoria, 1974-1976. In "Epidemiology and Crop Loss Assessment". Proceedings of A.P.P.S. Workshop, Lincoln College, August 1977: 31-1 to 13-6.

Sanderson, F.R. and J.E. Hampton. 1978. The role of the perfect states in the epidemiology of the common Septoria diseases of wheat. NZ Journal of Agricultural Research 21 (1978) 277-81.

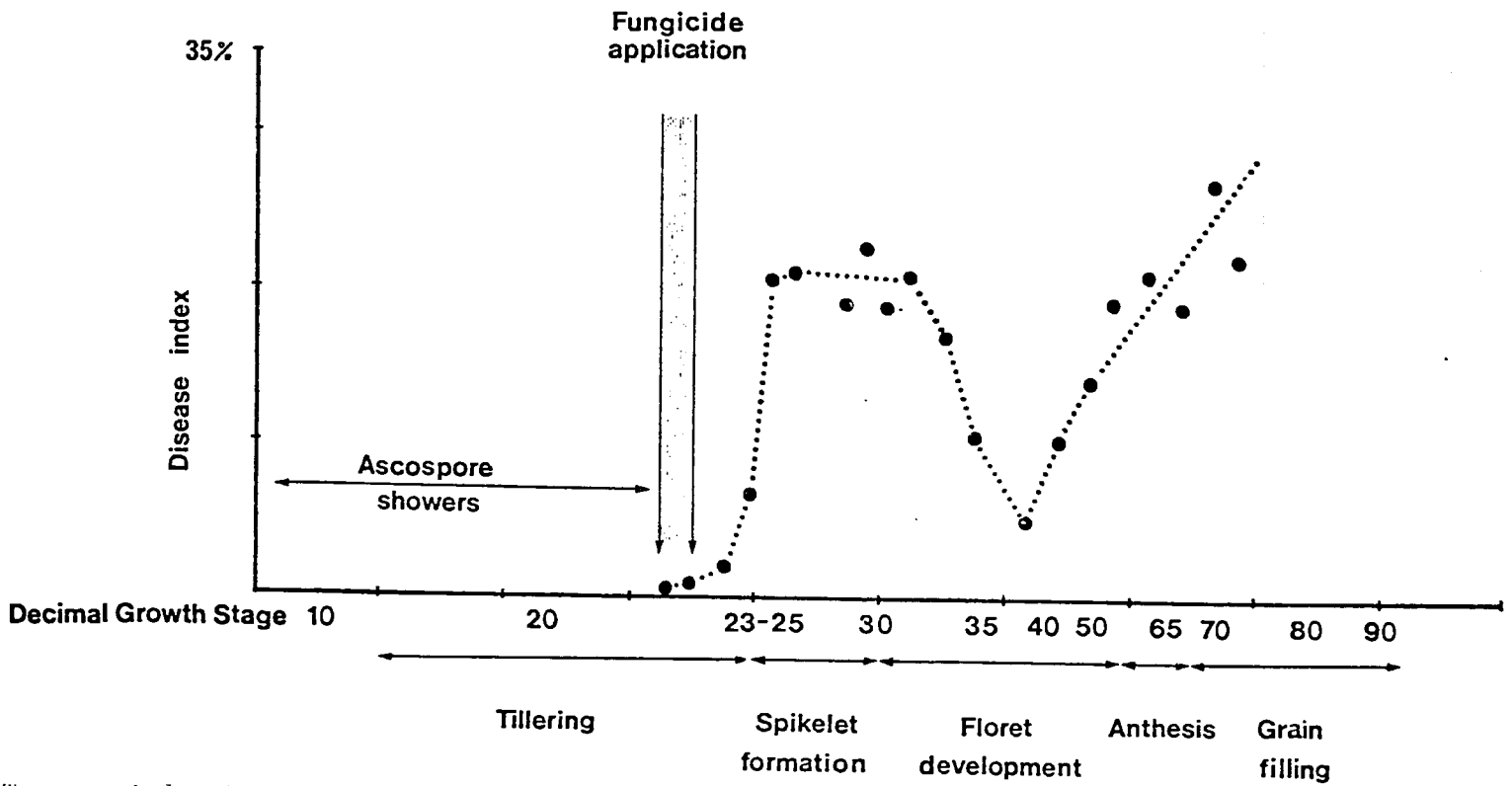

Figure 1. The two infection periods of speckled leaf blotch (Mycosphaerella graminicola) in New Zealand. The first which coincides with spikelet formation results in reduced seedling vigour and grain number. The second on the flag leaf is measured in reduced grain weight. A single spray, after ascospore showers have ceased, yet before infection builds up just prior to spikelet formation is suggested as an acceptable control strategy for this disease. The Disease index is the percentage difference in green leaf area between healthy plants (sprayed) and diseased plants (unsprayed).

WINTER WHEATS TOLERANT TO WHEAT STREAK MOSAIC

W. K. Pope, C. T. Liu, Wm. Willis, and S. T. Chang
United States

Abstract

Abundant wheat streak mosaic in early planted 1976-1977 winter wheat plots revealed a wide range of variety tolerance and moderately quantitative inheritance patterns with additive interactions for increased tolerance noted in crosses of PI 178383 with Cheyenne in ID5011, with Elgin in sub lines of Moro, and with Burt in CI 13837. Variety and population reactions are listed.

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"At Moscow, Idaho two acres of winter wheat plots planted early in the fall of 1976 adjacent to grass meadow developed high infection levels of wheat streak mosaic virus (WSMV)" (Chang, 1979).

S. T. Chang found good to fair tolerance to wheat streak mosaic in the snowmold tolerant wheat varieties 'PI 173440-Wanser', from G. W. Bruehl, Wash., in 'SM #4', 'SM #6', 'CI 14106', and 'CI 14107', from D. W. Sunderman, Idaho, in the Ark sib line 'ID5011', from the Moscow based program and in the commercial wheat 'Itana' which was used as the susceptible check for snowmold, Typhula and Fusarium spp. and stripe rust Puccinia striiformis, West.

In other portions of this field other varieties with high tolerance to WSM included: 'Bankuti 1205', 'Sel 101-178383', 'Burt-178383', 'Cheyenne-178383' (ID5046), several lines of 'Hussar-Hohenheimer/3*Triplet//Comanche', and 'Lely' and 'Mironoskaya 808' from the 1976 and 1977 International Winter Wheat Performance Nurseries. Tables 2-4 list other varieties with varying degrees of "intermediate" tolerance to WSM. 'Cheyenne' and 'Kharkof' were typical of wheats with a "low-intermediate" tolerance widespread in hard red winter wheats. Many western white wheats were severely damaged such as 'Nugaines' and 'Peck'. 'Daws' which has a PI 178383 parentage was much less damaged (Table 1). The Oregon wheats 'OR67205', OR68007', 'Stephens' CI 17569, and the Washington wheat 'Cerco' CI 15922, each with a European parentage, also had low damage, but were grown in a corner of the field that had lower WSMV infections so comparative rankings could not be made.

All selection groups involving one or more parent wheats that were tolerant to WSM, produced some surviving advanced generation progeny with at least the parental level of tolerance, (Table 5). This was "spectacular" from a plant breeding point of view; but meant only, that "genetics works", that there were good screening conditions, and that there probably had been unrecognized selection for tolerance to WSM in this same location in previous years.

University of Idaho, Moscow

Table 1. Ranking by head weights of selected wehat varieties grown under conditions of wheat streak mosaic at Moscow, Idaho in 1976-77.

Item	Position	Variety	CI no.	bundle	heads	Hd Wt / Bd Wt	No. Hd 2/	g/hd 2/	% seed over 6/64	Pedigrees:
1	3-15	ID33	-	230	97	.42	139	.85	57	Minn II/MC//Moran
2	2-1	Itana	12933	226	92	.41	124	.90	52	Bh/Rex//Cheyenne
3	4-19	Sprague	15376	202	86	.43	125	.56	-	PI 181268/Gaines
4	2-3	Daws	17419	210	82	.39	75	.87	53	Odin der./PI 178383 der.
5	3-11	ID70-1005	17254	238	76	.32	137	.45	47	Itana-65 sel.
6	3-8	Franklin	15317	230	74	.32	138	.44	34	Cnn *2/PI 178383
7	3-6	Ark	15286	143	72	.50	101	.80	31	PI 178383/Cnn//3*TD
8	4-6	Kharkof	1442	214	71	.33	138	.55	47	Intro. Russia
9	3-12	ID70-1008	17253	223	70	.81	148	.41	40	Pnc/Cnn//Td
10	3-7	Jeff	17270	170	69	.41	97	.72	69	It/Ko//PI 178383
11	4-22	ID72-5059	-	167	66	.40	149	.51	-	Nrn-10/Bvr//7* Bt/3/Bt-17
12	2-4	Hyslop	14564	176	66	.38	117	.53	27	Nd/Sel 101
13	4-10	Paha	14485	249	64	.26	89	.74	21	Su92/4*Omar
14	4-12	OR6882		228	63	.28	63	.84	-	Omar Mut./PI 178383/Omar//101
15	3-17	Hansel	17296	219	63	.29	178	.39	24	Dlm/PI 178383/Clm
16	3-19	WA5911	-	175	63	.36	152	.39	12	CI 9342/Itana
17	3-5	Ranger	15316	154	61	.40	123	.52	57	Wrr/Ko//PI 178383
18	3-13	Ark sib	17247	242	60	.25	111	.57	26	ID70-1004 17/Cnn//3*Td
19	3-22	WA5984	-	155	60	.39	94	.61	69	Bkt1205/Bt//14-53/1
20	3-21	WA5985	-	178	57	.32	70	.50	66	Bkt1205/Bt//14-53-1
21	4-33	Wanser	13844	152	55	.36	103	.54	32	Bt/Itana sel 34

Table 1. concluded.

Item	Position	Variety	CI no.	Wt g 1/ bundle	heads	Hd Wt / Bd Wt	No. 2/ Hd	g/hd 2/	% seed over 6/64	Pedigrees:
22	3-16	Cardon	17295	174	54	.31	145	.40	27	Dlm/PI 178383/Clm
23	4-25	UT819-096	-	228	52	.23	80	.63	19	Dlm/Clm//Bt-178383
24	4-27	UT819-188	-	147	52	.35	89	.58	-	Dlm/Clm//Bt-178383
25	4-14	Luke	14586	127	51	.40	129	.54	-	PI 178383 der./Sel 101
26	3-9	WA5835	-	183	51	.28	74	.45	48	Bez//Bkt1205/CI 13438
27	3-10	WA5836	-	146	48	.33	119	.36	17	Bez//CI 13438/BT
28	3-24	3/42 Bulk	-	147	48	.38	89	.57	69	Bez/Bt-178383//Ark
29	4-8	Moro	13740	192	48	.25	59	.44	21	PI 178383/2*Omar
30	4-9	Nugaines	13968	136	47	.35	82	.41	19	Nrn-10/Bvr//Of/Bvr/3/Bt
31	2-6	Yamhill	14563	150	45	.30	56	.66	51	Heines VII/Redmond
32	4-7	Elgin	11755	186	45	.24	58	.71	29	Gc/Hyb 128
33	3-18	MT6828	-	148	44	.30	120	.30	26	Burt-PI 178383
34	3-2	Faro	17590	119	43	.36	92	.53	13	Su92/3*Omar//Moro
35	4-24	OR7142	-	202	43	.21	55	.78	21	Su92/3*Omar//Moro
36	2-8	Barbee	17417	127	41	.32	78	.45	5	Omar/1834-3//17/CI 13431
37	3-23	A-WA/A	-	144	36	.25	91	.50	65	WA4765/2*ID5011
38	2-9	Lenore	17726	96	36	.38	64	.45	11	WA4765/Bt-PI 178383
39	4-17	OR6734	-	172	36	.21	67	.25	-	PI 178383/3*Omar
40	2-5	Peck	17298	136	34	.25	71	.44	9	Swedish type/2*Ngn
41	3-14	ID32	-	103	28	.27	62	.39	25	Nrn-10/Bvr/Tk/3/Dlm
42	3-1	Greer	17725	76	23	.30	68	.34	10	WA4765/Bt-PI 178383
43	2-7	Raeder	17418	101	23	.23	52	.31	13	Gns//PI 178383/CI 13431

1/ Average of four samples each from two feet of row from the same plot. 100g heads = 60 bu/a (=3600 kg/ha).
2/ Average of two samples only.

Table 2. Ranking of wheats for tolerance to wheat streak mosaic as grown at Moscow, Idaho in 1976-77.

Item	Variety	CI	Tolerance (1-6)
A.	Varieties with high tolerance to WSM		
1.	Bankuti 1205	-	1
2.	CI 9342	9342	1
3.	Lely (IWWPN 76-9)	-	1
4.	Mironovskaya 808 (IWWPN 77-19)	-	1
5.	PI 173440-Wanser	-	1
6.	Sel 101/PI 173440	-	1
B.	Varieties with intermediate tolerance to WSM		
7.	Ponca	12128	2
8.	Itana	12933	2
9.	Hs/Hh//3*Tlt/3/3*Cnn	-	2
10.	Cheyenne/Lee	-	2
11.	American Falls Turkey	-	3-4
12.	Ridit	6703	3
13.	Wasatch	11925	3
14.	Ridit*2/Cheyenne	-	2.5
15.	Sm #4, Sm #6	-	3
16.	CI 14106, CI 14107	-	3
17.	Arbon (der. of CI 14106)	17746	3
18.	ID33	-	3
19.	WA6239 (Burt-Falco/Burt)	-	3
20.	WA6243 (Itana cross)	-	3.5
21.	Kharkof	1442	4
22.	Cheyenne	8885	4
23.	Many entries in IWWPN (see Tables 3 and 4)		
24.	Many varieties with low tolerance (see Table 1)		
C.	Derivatives of PI 178383		
25.	PI 178383	-	3.5
26.	Burt/PI 178383	13837	2
27.	Cheyenne-PI 178383	-	2
28.	ID5011 (Ark sib)	17246	2
29.	Ark	15286	3.5
30.	UT88616	-	3
31.	Jeff, Franklin, Ranger 17270,	15317, 15316	4
32.	Daws	17419	4
33.	Luke	14586	5

Table 3. Grain yield of the Eighth International Winter Wheat Performance Nursery grown in a wheat streak mosaic situation at Moscow, Idaho in 1976-77.

1977 Nebraska Number	Code Number	Variety	Yield (g/10ft)
1	1703	Maris Templar	250
2	1702	Maris Huntsman	115
3	0403	Martonvasar 2	330
4	1606	Dunav 1	180
5	0507	Flavio	winterkill
6	0404	GKF 2	170
7	1607	Biserka	200
8	2301	TRS 237	165
9	0704	Lely	325
10	1025	Sentinal	295
11	2401	Rashid	winterkill
12	0305	Kormoran	55
13	1502	Kitakomi-Komugi	35
14	0205	Talent	115
15	1201	Bezostaya 1	240
16	0602	Lerma Rojo 64	winterkill
17	2501	Bordenave Puan Sag	65
18	2204	Galiafen	winterkill
19	0405	GKF 8001	110
20	0406	Martonvasar 3	150
21	1026	Oasis	50
22	1302	WWP 7147	120
23	1027	Sage	70
24	1205	Odesskaya 51	120
25	1206	Priboy	not grown
26	1804	F26-70	not grown
27	1028	WA5829	65
28	1029	NE68719	100
29	1001	Atlas 66	70
30	1003	Blueboy	285

Table 4. Ninth International Winter Wheat Performance Nursery grown in a wheat streak mosaic situation at Moscow, Idaho in 1976-77.

1977 Nebraska Number	Code Number	Variety	Yield (g/10ft)	% seed over 6/64
1	1001	Atlas 66	50	-
2	1206	Priboy	210	-
3	1003	Blueboy	210	-
4	1205	Odesskaya 51	175	-
5	1804	F26-70	75	-
6	1028	WA5829	80	-
7	1027	Sage	145	-
8	1201	Bezostaya 1	180	-
9	0405	GKF 8001	145	12
10	0406	Martonvasar 3	300	37
11	1029	NE68719	60	26
12	2204	Galiafen	winterkill	-
13	2501	Bordenave Puan Sag	25	55
14	1026	Oasis	75	14
15	0507	Flavio	winterkill	-
16	1302	WWP 7147	255	48
17	1030	NE73640	185	30
18	1031	Lindon	225	12
19	1208	Mironovskaya 808	390	61
20	1207	Krasnodarskaya 39	150	84
21	2003	Sandovo 1	240	51
22	1805	F53-70	120	52
23	1806	F54-70	65	55
24	1807	Iulia	190	45
25	1209	2109-36	250	65
26	1609	Zg 4240/73	200	35
27	1608	Zg 887/73	winterkill	-
28	1611	Zg 4364/73	100	10
29	1610	Zg 4293/73	130	36
30	0602	Lerma Rojo 64	winterkill	-

Table 5. Seed size classification of advanced generation wheat selections grown under conditions of wheat streak mosaic at Moscow, Idaho in 1976-77.

Item		Populations	of lines	% seed larger than 6/64 inch screen								
				10	20	30	40	50	60	70	80	90
1	Parent	PI 178383	1				1					
2	Parent	Cheyenne	1		1							
3	Parent	Am Falls Turkey lines	6	5		1						
4		Ridit/4*Cheyenne	8		3	2	3					
5		Hussar/5*Cheyenne	5		1	1	3					
6		Rex-Rio/7*Cheyenne	4		2	2						
7		PI 178383/Cnn//3*Tendoy	5		2		1	1	1			
8		Td/Rdt//2*Triplet	5		2		1	1	1			
9		Rex-Rio/5*Cnn//Am Falls Tk	13		2	3	2	4	2			
10		Rex-Rio/7*Cnn//Am Falls Tk	9		1	2	3	1		2		
11		Cheyenne/Lee	18			3	4	1	7	2	1	
12		Nrn-10/Staring//2*Cnn	[illegible]		5			3	1			
13		Nrn-10/Staring//Am Falls Tk	17	5	2	4	3		3			
14	Parent	Bankuti 1205	2							2		
15		Bankuti/2*Tenday	14					6	8		1	
16		Bankuti/2*Itana-65	11					3	4	2	1	1
17		Hu/Hh//3*Tlt/3/Cnn	17			1	1	1	7	5	2	
18	Parent	Sel 101/PI 173440	1								1	
19		Sel 101/173440//ID5006/ID5011	9					3	3	2	1	
20		Bez/Bt-1788383//Ark	26	4	8	6	2	2	4			
21		Bez/Bt-178383//CI 9342	37	7	2	5	6	7	4	2	4	

In large bulk populations with one or more WSM tolerant parents such as Bezostaja/Burt-178383//CI 9342, there was a recovery of 40 to 60 percent large seed, implying the recovery of genotypes with good tolerance to WSM.

Interpretation of virus damage symptoms. WSM symptoms ranged from wheat plots with many dead plants and headless tillers and varying degrees of stunting, to types seemingly little affected. Leaf colors varied from bright yellow to pale green with and without mottling and with little correlation to final yield. Curled flag leaves that entangled the emerging heads were common in many varieties. Early varieties were favored. Some late seemingly highly tolerant varieties such as Burt-178383 produced good plant growth but ended up with small heads and shrivelled seeds as though suffering from drought. The general appearance of all but the most tolerant varieties was one of continued stress with wheats of different genotypes giving varying degrees of opposition to the virus infection.

The damage from WSM in the first half of the field was assessed by taking physical measurements on four samples each representing two feet of row from each plot such as shown in Table 1. The rest of the field was classified visually and from harvested grain samples. Seed was stratified over a 6/64 inch (2.38 mm) slotted hand screen to characterize plot samples and to help recover within-line superior segregates. Seed size was a relatively non-varying measurement, for in 12 duplicated plots in the Bankuti crosses seed size varied only 6 percentage points within lines. Most varieties and lines were represented by only single plots and the value judgements of Table 2 are based on plots paired within a small area.

One unresolved puzzle in this planting was a high level of stripe rust infection that built up in the fall and then disappeared during the open winter. The potential interaction between these two diseases was ignored when it was noticed that the range of tolerance to WSM occurred in wheats having a wide range of known tolerance to stripe rust.

Genetic Evidence:

1) Segregation: Chang (1979) in a thesis study found that CI14106, which is more tolerant to WSM than Cheyene, showed a segregation pattern in a test cross to the highly susceptible Peck, requiring a minimum of two or three genes conditioning tolerance to WSM.

2) Variety genotype mixtures: The old variety 'Wasatch' had three different relatively tolerant phenotypes in a sample of five head rows. The visibly susceptible 'Sprague' which had a very yellow leaf, showed three different slightly greener phenotypes in five family sub-groups. The susceptible club wheat 'Moro' had one distinctly green row in a sample of five head rows. This may have been a non-effective difference for the seed of this row was still shrivelled much as that of the other rows. The

yield size plot of Moro had a "clumpy" appearance attributed to the difference in plant and head size in the mixture of partially tolerant and susceptible plants. The varieties 'Yamhill' and OR67205 had a wide range in head sizes implying either genotype mixtures for a range in tolerance to WSM or a wide difference in environmental effect between early and late tillers within the same genotype.

3) Additive interactions: PI 178383 had an intermediate tolerance to WSM with a conspicuous diseased phenotype of a mottled early drying leaf that was recognized in many progeny including 'Ark', 'Jeff', and Moro. The genes controlling this level of tolerance to WSM were additive with those from Cheyenne in Cheyenne/178383 and in the backcross that became ID5011, a sib of the commercial variety Ark (178383/Cnn//3*Tendoy; Tendoy = Rex-Rio/4*Cnn). Ark had the leaf type of PI 178383 and was classed as less damaged than Cheyenne. ID5011 and one other of seven sib lines were vigorous green leafed wheats without the early drying leaf of PI 178383. This two step increase in tolerance to WSM above that in Cheyenne would require a two gene contribution from PI 178383.

These genes from PI 178383 were also presumably additive with 'Burt' CI 12696 (not grown) in Burt-178383 and with 'Elgin', or 'Omar' CI 13072 in the green leafed subline of Moro (178383/2* Omar).

The wheat 'WA5911' (CI 9342/Itana) was less tolerant to WSM than either parent implying unfavorable trangressive segregation from different genes in the two parents.

4) Cheyenne crosses: Many Cheyenne crosses produced higher than Cheyenne levels of tolerance to WSM including crosses to the spring wheats 'Lee', a 'Marquis type', the Australian wheat 'Festival' PI 206364, the winter wheat 'Norin-10-Staring' CI 13273, 'Ridit', 'Ridit/2*Triplet' (ID5044), and 'American Falls Turkey' (ID5045). The last three crosses were interpreted as having additive interactions. The parent varieties in the other crosses were not grown.

In the Bankuti crosses to Tendoy and Itana-65 and in the cross of Sel 101-173440 to ID5006/ID5011 (Table 5, items 15, 16, & 19) all the progeny that were saved had higher than Cheyenne levels of tolerance to WSM. This implies that the highly resistant Bankuti and Sel 101-173440 also contain the Cheyenne type genes for all the other parents including 'ID5006' CI 17428 (Norin 10 Staring/2*Cheyenne) were Cheyenne derivatives.

Conclusion. There is a background of genes conditioning low to moderate tolerance to wheat streak mosaic virus in many hard red winter wheats, in hard red spring wheats, and in at least six wheats used as sources of resistance to snowmold. In crosses and selections made for other purposes some of those combinations produced increased tolerance to WSM. Presumably further recombinations among these genes could provide still higher levels to tolerance to WSM.

This was similar to the pattern seen for additive interactions for resistance to stripe rust in these and similar populations at this location in the 1960's (Pope, 1968).

Literature Cited

Chang, S. T. 1979. Evaluation of wheats with differential tolerance to wheat streak mosaic. M. S. Thesis., Univ. of Idaho. 41pp.

Pope, W. K. 1968. The inheritance of minor genes for resistance to stripe rust in wheat. In Proc. 3rd Int. Wheat Genet. Symp. (Aust . Acad. Sci. Canberra): 251-257.

REACTION OF YUGOSLAV WINTER WHEAT VARIETIES TO SOME FUNGAL DISEASES AND INSECT PESTS

B. Kostic, S. Stamenkovic, M. Pribakovic, and V. Momcilovic
Yugoslavia

Abstract

In Yugoslav climatic conditions several pathogens occur on winter wheat crops with the following considered the most common: Erysiphe graminis tritici, Fusarium spp., Puccinia recondita tritici, Septoria nodorum, Septoria tritici, Gaeumannomyces graminis, Cercosporella herpotrichoides, and Ustilago tritici.

Of the insects influencing wheat production in Yugoslavia the most important are Zabrus tenebrioides, Eurygaster spp., Opomyza florum, Leptohylemyia coarctata, Lema melanopa, Aphididae, Agromyzidae, Chaetocnema aridula, Cephus pygmaeus, Thrips tritici.

Reaction of new Yugoslav winter wheat varieties to some of the pathogens was tested in several localities over the country in 1976, 1977 and 1978. Differences among the varieties were found to exist, but none of the varieties has shown extreme susceptibility.

Since the wheat is one of the most important crops in Yugoslavia, special attention is paid to its growing. An intensive home wheat breeding program has provided new high-yielding and high quality cultivars.

Wheat yield performance is influenced, among other factors, by diseases as well as insect pests whose development is enhanced by favorable environmental conditions of the country.

To become acquainted with the reactions of home-bred wheat varieties to pathogens and insects, a number of macrotrials have been surveyed. Out of 259 trials set up in the wheat-growing regions, 79 were planted in 1976, 88 in 1977, and 92 in 1978. Their distribution is shown in Figure 1.

At least 2000 m^2 were occupied by each cultivar in the trial. Intensive agricultural practices analogous to those performed at state farms were applied.

Disease and insect surveys were done in April and June. The grading of rusts and powdery mildew severity was based upon Cobb's scale, Septoria diseases on Prescott's scale, while for Fusaria, diseased heads per 1 m^2 were counted. For rusts and mildew, the coefficients of infection were calculated from severity and response.

Institute of Field and Vegetable Crops, Faculty of Agriculture, Novi Sad

Figure 1. Distribution of wheat trials.

The populations of insects were collected by net-catcher and in surface soil samples and analyzed in the laboratory.

In the growing seasons 1976-1978, twelve fungal diseases were present on the wheat plants.

Powdery mildew (Erysiphe graminis f. sp. tritici) was most common except in some dry areas in the south of the country.

Leaf rust (Puccinia recondita f. sp. tritici) was observed all over the wheat-growing regions but with a low severity. The disease was the least intensive in 1977.

Stem rust (Puccinia graminis f. sp. tritici) was usually sporadic, primary infection foci not causing the epidemics.

Yellow rust (Puccinia striiformis f. sp. tritici) occurred sparsely. In the years of survey it was found in some localities only.

Head blight of wheat (Fusarium spp.) was, strictly speaking, economically most important. Disease levels in 1976 and in 1977 were somewhat lower than in 1978.

Leaf blotch or speckled leaf blotch (Septoria tritici) and glume blotch (Septoria nodorum) occurred regularly, the latter one being prevalent.

Of the root rot fungi, Ophiobolus graminis (Gaeumannomyces graminis) known as take-all was more common than Cercosporella herpotrichoides, causing foot rot or stem break.

Loose smut (Ustilago tritici), leaf spot (Cochliobolus sativus) and ergot (Claviceps purpurea) were of minor importance because of a low level of occurrence.

The following insect pests were frequently found on the wheat crop in large-plot trials: corn ground beetle (Zabrus tenebrioides), sunn pests (Eurygaster austriaca, E. maura), wheat flies (Opomyza florum, Leptohylemyia coarctata, Phorbia securis), and cereal leaf beetle (Oulema melanopus).

Corn ground beetle occurred exclusively in trials planted in plots precropped by wheat. There was a difference in the severity of attack in relation to the regions but not in relation to the varieties.

The most extensive damage on the crop in large-plot trials was caused by wheat flies, especially Opomyza florum, the frequency of which was higher than usual on the trials of early sowing.

Wheat bulb fly (Leptohylemyia coarctata) was regularly present on the varieties whose seedlings emerged at the end of January and/or at the beginning of February.

Late wheat short fly (Phorbia securis) was found in all trials but the density of its population was quite low.

Cereal leaf beetle caused considerable damage in only some of the trials although it was present in almost all of them.

Some other insect pests as aphids (Aphididae), leaf miner flies (Agromyzidae), Anisoplia spp., wheat flea beetle (Chaetocnema aridula), wheat stem sawfly (Cephus pygmaeus) and wheat trips (Haplothrips tritici), were also found in the wheat trials, but the damage they caused was negligible.

As was mentioned before, reaction of the cultivars to the diseases was studied in the large-plot trials under natural infection. Thirty varieties were sown in 1976, twenty in 1977, and twenty-four in 1978. Data are presented in Tables 1, 2, and 3. From the readings at all localities, the average coefficient of infection was calculated for the rusts and powdery mildew.

In 1976 the varieties showed good resistance to powdery mildew, their coefficients of infection being low. The highest ones were found for Kavkaz, NS 1321 and NS 1463/1. The next year, disease severity was considerably higher but still not at a level to cause large damage. A little higher coefficient of infection was found for Novosadska 100, NS 1321, Zlatna Dolina, Partizanka, Banija, Sava and Drina than for other varieties. Mildew severity in 1978 was similar to that in the previous year. Only five cultivars had the coefficient of infection higher than 20.

Table 1. Reaction of wheat cultivars to diseases in large plot trials in 1976.

No.	Cultivar	Powdery mildew	Stem rust	Leaf rust	Fusarium spp.	Septoria spp.
1.	Sava	2.4	t	0	2.0	1.4
2.	Biserka	2.3	t	0	1.6	1.4
3.	Drina	2.8	t	0	1.3	1.7
4.	Partizanka	3.5	t	0	0.7	1.3
5.	Nova Banatka	1.2	t	0	0.9	1.4
6.	Sremica	1.4	t	t	1.8	1.8
7.	Novosadska Crvena	4.0	t	t	0.9	1.3
8.	Novosadska Rana 1	1.7	t	t	1.3	1.8
9.	Novosadska Rana 2	2.2	t	t	1.1	1.7
10.	Novosadska Rana 3	2.5	t	0.1	1.7	2.0
11.	Fruskogorka	3.0	t	t	1.0	1.4
12.	Banacanka 1	3.4	t	t	0.8	1.4
13.	Vojvodjanka	0.9	0	t	3.6	1.4
14.	Bacvanka 1	3.3	0.2	t	1.2	1.3
15.	Tisa	3.9	t	t	7.2	0.6
16.	NS 1321	16.7	1.1	0.7	2.2	1.3
17.	Zlatna Dolina	8.0	t	t	1.0	1.3
18.	Banacanka 2	1.2	t	t	8.0	0.8
19.	NS 1481/1	7.0	0	t	1.7	1.0
20.	Dobro Polje	6.7	t	t	20.1	1.6
21.	NS 1463/1	12.2	2.3	3.2	14.2	1.6
22.	Dunav	0.8	2.5	1.2	0.3	2.7
23.	Backa	4.0	t	t	1.1	1.0
24.	Panonija	2.0	0	0	0.1	t
25.	Libelula	1.1	t	t	0.3	1.0
26.	Bezostaja 1	7.5	t	t	1.5	2.3
27.	Kavkaz	20.0	t	15.0	0.7	1.0
28.	Kragujevacka 56	3.2	t	15.8	30.3	1.7
29.	Morava	t	t	0	0.5	2.2
30.	Kosmajka	t	t	t	0.6	2.0

The severity of stem rust over three seasons was low also. In 1976 it occurred in traces on almost all entries while in the next two years it was observed on some of them only.

The situation with leaf rust in 1976 and 1977 was similar to that of stem rust. It was found only in traces. The rust occurred more intensively in 1978. The highest coefficients of infection were found for the cultivars NS 7000, Zrenjaninka, Becejka, Sremica and Banija.

Fusarium head blight of wheat was present on all wheat cultivars in 1976. The number of infected heads ranged from 0.1 to 30.3 per 1 m^2. In 1977 the disease was less intensive. It was observed on some of the entries only. In 1978 it was found on all cultivars. The number of infected heads varied from 1.6 to 6.3 per 1 m^2.

Table 2. Reaction of wheat cultivars to diseases in large plot trials in 1977.

No.	Cultivar	Powdery mildew	*Septoria* spp.
1.	Sava	25.0	0.8
2.	Biserka	17.0	0.7
3.	Drina	23.5	0.8
4.	Partizanka	29.0	0.8
5.	Nova Banatka	15.2	0.6
6.	Sremica	10.9	0.9
7.	Novosadska Crvena	21.2	0.7
8.	Novosadska Rana 1	21.5	0.7
9.	Novosadska Rana 2	11.1	0.7
10.	Novosadska Rana 3	18.6	0.6
11.	Fruskogorka	19.2	1.0
12.	Banacanka 1	19.1	0.5
13.	Vojvodjanka	19.3	0.9
14.	Bacvanka 1	22.3	0.7
15.	Tisa	13.8	0.9
16.	NS 1321	42.7	1.0
17.	Zlatna Dolina	31.8	0.5
18.	Banija	27.5	0.8
19.	Novosadska 100	45.2	1.1
20.	NS 1420	23.2	0.9

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Leaf and glume blotch occurred regularly on all entries in the trials but with low levels of infection.

Table 3. Reaction of wheat cultivars to diseases in large plot trials in 1978.

No.	Cultivars	Powdery mildew	Leaf rust	Fusarium spp.	Septoria spp.
1.	Sava	11.6	11.1	3.6	2.5
2.	Biserka	9.8	13.0	3.6	2.7
3.	Drina	10.3	12.1	3.3	2.7
4.	Partizanka	13.5	7.3	2.4	2.1
5.	Nova Banatka	9.2	6.0	1.4	1.9
6.	Sremica	19.0	22.0	1.5	1.7
7.	Novosadska Crvena	11.3	9.5	2.3	2.6
8.	Novosadska Rana 1	10.4	10.1	3.9	2.7
9.	Novosadska Rana 2	10.0	12.0	3.4	2.8
10.	Novosadska Rana 3	9.8	11.1	4.6	2.9
11.	Fruskogorka	11.5	6.9	2.9	2.3
12.	Banacanka 1	10.9	6.0	3.4	1.9
13.	Banija	15.5	22.0	6.3	3.6
14.	Macvanka 1	11.1	7.1	1.6	2.3
15.	Zrenjaninka	26.7	26.3	3.0	2.7
16.	Becejka	24.3	24.3	2.9	1.9
17.	Novosadska Brkulja	25.0	19.6	2.3	2.1
18.	Macvanka 2	11.5	7.5	3.0	2.2
19.	Balkan	9.9	6.9	4.2	2.3
20.	Posavka 1	16.8	5.8	3.6	2.2
21.	Posavka 2	12.3	6.4	4.9	2.3
22.	NS 7000	23.7	42.7	2.5	2.2
23.	Kozara	21.3	19.0	2.3	1.3
24.	NS 1201	18.0	20.7	2.1	1.3

Conclusions from these observations may be stated as follows:

In the country-wide large-plot trials of wheat, several diseases and insect pests occurred but their severity varied from season to season.

Powdery mildew, leaf blotch and glume blotch were most common, while Fusaria head blight was most dangerous.

There was little difference in reaction among the cultivars, whose resistance under field conditions could be considered as satisfactory.

No differences among cultivars in reaction to insect pests were observed in field trials, but there were differences in the density of the populations of insects.

YELLOW WHEAT FLY, OPOMYZA FLORUM FABR., (Opomyzidae, Diptera) A NEW WHEAT PEST IN YUGOSLAVIA

Sreten Stamenkovic
Yugoslavia

Abstract

Yellow wheat fly (O. florum Fabr.) is a new wheat pest in Yugoslavia. Its imago is yellowish-brown in color, 3.5-4.5 mm long. Transparent wings are longer than the body, with characteristic spots which facilitate identification of the species.

The development of the larva lasts for 30-40 days, passing through three larval instars. An adult larva is 7-8 mm long. The pupa is light brown in color, 4.5-5.5 mm long. Its development lasts for 20-25 days.

In our conditions, the imago flies and mates intensively during October. After mating, the female lays eggs into the soil, close by the wheat plants. The egg overwinters there. In early March, the larva comes out, climbs to the top of the plant to descend by the central leaf inside the bottom part of the wheat plant. It finishes the descent in two spiral circles around the stem making the damage characteristic for this species. Feeding on the plant, the larva severs the conductive vessels and destroys the plant tissue, causing first the wilting of the central leaf, then of the entire plant.

The larva finishes its development in late April or early May turning into the pupa. The imago flies out at the end of May and during June. It is sexually immature at the beginning and dwells on the inflorescences of different weed species. It comes sexually active in October, mating and laying of eggs in the plots of early-planted and already-emerged wheat. The species has one generation annually.

In the period 1977-1979, the species was rather numerous in many localities around Vojvodina. It was especially numerous in 1978, causing considerable damage on early-planted wheat. It also attacks barley, but on a smaller scale.

Introduction

The yellow wheat fly is distributed in many European countries. Recent reports on this species were made by Latteur (1974) and Pavlyuchuk (1975).

There are no details on the occurrence of the pest in Yugoslavia and damage inflicted by it. The first information was reported by Tesic (1966) and Petrik et al. (1966). Since the pest has become more harmful in recent years in Voyvodina, we decided to study its bioecology and distribution.

Faculty of Agriculture, Institute of Field and Vegetable Crops, Novi Sad

Method

The life cycle of the pest was observed in the period 1977-1979. Observations in wheat fields were made from October to June. From July to September, the pest was observed in wooded places where the species spends its summer reproductive diapause. The imago flight to wheat fields, mating, and egg laying were observed in the fall. In spring, we followed larval development, extent of damage, pupation, and the flight of imagoes to the places where they spend the summer diapause. During summer, we followed the behaviour of imagoes in these places.

Results and Discussion

Life cycle. Under conditions of Voyvodina, the imagoes fly and mate intensively in October. After mating, the females lay eggs in the soil close to the wheat plants. The eggs overwinter there and the larvae develop in early March. Their development lasts for 30-40 days, passing through three larval instars. A mature larva is 7-8 mm long.

The larvae finish their development by the end of April and turn into pupae in early May. The pupae are light-brown, 4.5-5.5 mm long. Their development lasts for 20-25 days.

The imagoes are found in the field during the end of May through June. They are brownish-yellow, 3.5-4.6 mm long. Transparent wings are longer than the body, with characteristic spots which facilitate the identification of the species. Soon after they appear, the imagoes fly from wheat fields to wooded places, mostly near rivers or channels where, in the shade, the relative air humidity is always high and the summer temperatures are low. The imagoes stay there from July to September, frequenting the inflorescences of different weeds. They are sexually immature, being in reproductive diapause.

In early October, the imagoes again become active and fly to early-planted wheat fields where the wheat already has emerged. Soon after, they become sexually mature, mate, and oviposit, thus repeating the cycle. The species has only one generation annually.

Symptoms of damage. During March, the larvae develop, climb to the top of wheat plants and descend by the central leaf inside the bottom part of the stem. They finish the descent in two spiral circles around the stem, making the damage characteristic for this species. Feeding on the plant, the larvae sever the conductive vessels and destroy the plant tissue causing at first the wilting of the central leaf and then the entire plant.

In the three-year research period, damage was recorded around Voyvodina on early-planted wheat. Damage was most extensive on the crop planted before October 10. Yield reduction ranged from 12 to 46%.

Conclusion

In the period 1977-1979, the yellow wheat fly (O. florum) was fairly frequent in the region of Voyvodina. It was especially frequent in 1978 when it inflicted considerable damage on early-planted wheat. It also attacks barley, but on a much smaller scale.

References

Latteur, C. 1974. Yellow small grains fly (Opomyza florum Fabricius, Diptera, Brachycera, Opomyzidae). (In French). Revue de l'Agriculture, No. 4:861-869.

Pavlyuchuk, M. B. 1975. Opomyza on winter wheat in the Stavropolysk region and influence of the cultural control on its injuriousness. (In Russian). Abstract of doctoral thesis, pp. 1-21.

Petrik, C. et al. 1966. Pests and diseases of field crops in Voyvodina during 1965, and forecast for their occurrence in 1966. (In Serbo-Croatian). Contemporary Agriculture XIV:3:305-331, Novi Sad.

Tesic, T. 1966. Diptera on Small Grain Crops in Serbia. (In Serbo-Croatian). Contemporary Agriculture XV:11-12:409-414, Novi Sad.

PHYSIOLOGY - ITS ROLE IN WHEAT BREEDING

Dale N. Moss
United States

My assignment today is to discuss the role of physiology in plant breeding. We have heard already and will yet hear in this conference many reports on how to conduct successful breeding programs. Wheat breeders have been and continue to be remarkably successful. If physiology has a place in wheat breeding then it must impact on these already successful programs. In what way could that happen?

To visualize a role for physiology let us look at the breeding process itself. A breeder must: 1) select two parents which he intends to cross; 2) make the cross; 3) grow out the progeny, and allow genetic segregation to occur over generations to get a desired homogeneity; 4) test certain homogenous lines in various environments and over years; 5) choose one or more that perform well to release as a cultivar; 6) increase the seed to commercial quantities. Where in that process is there a role for a crop physiologist?

About a year ago I had an Australian wheat breeder, whom I had never met before, come into my office and his first words to me, even before hello, were, "I understand you are a real, live crop physiologist". Now I have become accustomed, over the years, to a delightful openness on the part of my Australian friends, but I will confess that the incredulous tone in the voice of this complete stranger put me a little on guard. "I hope I can answer 'yes' to at least part of that statement," I replied. "Then list for me," said my new friend, "just one wheat variety, or one variety of any crop, for that matter, that came about because a physiologist told a plant breeder which two plants to cross, or after making a cross, which one of the progeny to choose." This gentleman had a valid point. I don't know of any such variety. Why then will I take the risk of standing before a group of the world's foremost plant breeders and talk about a physiologist's role in wheat breeding in the future? The answer I give to that question is that, given the awesome task we face of feeding the world's billions, we must learn how to do the impossible, and do it quickly.

Let's look carefully at the breeding process and see if we can visualize <u>any</u> role for a physiologist.

Foremost in the role that physiology can play in the breeding process is helping us understand how plants grow and how yield is obtained in various environments.

Recall with me some of the steps that led to the "Green Revolution". When Orville Vogel, and later Norman Borlaug, began searching for new yield potential in wheat, they knew that high quality wheat contains high concentrations of protein and protein

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Oregon State University, Corvallis

contains nitrogen. Thus, to obtain high yields a grower must apply ample nitrogen fertilizers. However, when nitrogen was applied to varieties of wheat available in the 40's and 50's it grew tall and lodged. Lodged wheat did not produce high yields. Thus the initial search was for a short, stiff straw, a strictly morphological component of a high yielding plant. Not all short strawed genotypes were high yielding, however. The key to building in the ability to yield well was to build in the capacity of utilized nitrogen, a strictly physiological factor.

Dr. Borlaug sought not only high yield, but, since he hoped to have his wheat cultivars do well in many countries, he sought also wide adaptability. He recognized that one of the characteristics of wheat varieties was that they flowered in response to day-length. To be able to move genotypes latitudinally it would be necessary to remove this physiological sensitivity to day-length. Thus, the Mexican wheats which have had such an impact on wheat yields everywhere were selected on the basis of an understanding of specific physiological traits.

Can physiologists identify other traits which are yield barriers in wheat? Certainly the opportunities are numerous.

In the Crop Science Department at Oregon State University in Dr. Kronstad's group, one of the problems which had been identified in wheat production on many soils is aluminum toxicity. Along with P. C. Kerridge, a graduate student, Dr. Kronstad devised a system of growing seedling wheat plants in nutrient culture, exposing them for a short period to high aluminum concentrations in the medium and then returning them to a normal culture medium (Kerridge and Kronstad, 1968). Seedlings susceptible to aluminum were not able to survive this treatment, while tolerant seedlings were not affected seriously. This procedure provided a means of classifying seedlings of segregating populations for their tolerance to aluminum. This same treatment was used by Carlos Camarge, a student who followed later in Dr. Kronstad's program, to classify genotypes and study inheritance of tolerance to high aluminum in soils (Camargo, et al., 1980).

These are examples of use of knowledge by plant breeders themselves of specific physiological responses in plants. It is highly probable that much of the effect of physiology will be in that way--just as much of the use of knowledge of plant pathogens is made by the plant breeder without the direct involvement of a plant pathologist. Perhaps more training in physiology and biochemistry on the part of future plant breeders will be one of the pathways that will tie the disciplines of breeding and physiology together.

Are there other levels of involvement between physiology and breeding that could be beneficial to the breeding process? I faced that question directly in 1967 when I joined the faculty of the Department of Agronomy and Plant Genetics at the University of Minnesota. In discussions with the wheat breeder, Dr. Robert Heiner, and the barley breeder, Dr. Donald Rasmusson, we evolved

a program which we called "Plant Design Research". We summarized the process in four steps: 1) identify yield limiting factors; 2) find genetic variability for those traits (this could also involve finding marker genes to make visual selection possible or devising tests which were simple and accurate enough to at least put a plant in low or high categories for those traits); 3) determine heritability for those traits; 4) incorporate the trait into new cultivars.

Steps 3 and 4 of this process are not different from any breeding program; the physiology input, as we viewed it, would be necessary to identify limiting factors and to help the plant breeder find genetic diversity for limiting traits.

Perhaps it will be enlightening to our discussion to review our experience in the area of photosynthesis. When we began our program we did not know what factors were limiting yield in wheat and barley. It was obvious, however, that yield could never be greater than the net photosynthesis and a number of different lines of evidence suggested to us that, if we could develop cultivars which had greater photosynthetic capacity, we could use that capacity to build into the cultivar a greater capacity for grain yield.

In those early experiments at Minnesota, we knew nothing about the yet-to-be-discovered differences in biochemistry of photosynthesis in C-3 and C-4 plants. What we did know is that maize leaves were strikingly more efficient in utilizing light than were wheat leaves. We asked ourselves, "If screened widely, could we find a wheat plant which would respond to light with the efficiency and high rate of CO_2 fixation such as found in corn?" The problem we faced in answering that question is that we had to learn how to screen large populations of wheat plants for photosynthetic response quickly and accurately.

We knew that the carbon dioxide compensation points were strikingly different between wheat and maize. Using that as a basis, we devised a simple screening system which would differentiate between seedling plants in their ability to take up carbon dioxide (Menze, et al., 1969). The system involved putting corn and wheat seedlings together in a closed system under constant illumination and letting them compete for the carbon dioxide which the system contained. If corn alone were in the system, the CO_2 concentration would quickly drop to zero; with wheat alone the compensation would be at about 50 ppm. With both plants in the systems, the CO_2 concentration was 20 ppm or less. At that concentration, the corn seedlings still had some photosynthesis; in contrast, the wheat seedlings were always losing CO_2.

After three days in the system the wheat seedlings exhibited a general chlorosis and by six days they were dead. If a wheat plant should have the desired photosynthetic characteristic, however, it would remain alive in the system. This system was 100% accurate in distinguishing between the kinds of photosynthetic

systems plants had. It was simple, and easily conducted in the weekly routine of working. Plants were put in every Monday, and evaluated every Friday. Using that system we screened many tens of thousands of wheat seedlings, grown from seed of material which had several cycles of radiation, in an attempt to identify maize-type photosynthesis in wheat plants. None were found. Therefore breeding progress could not be made because genetic variability for the particular trait was not available, even though we believed that greater photosynthesis would lead to greater yield.

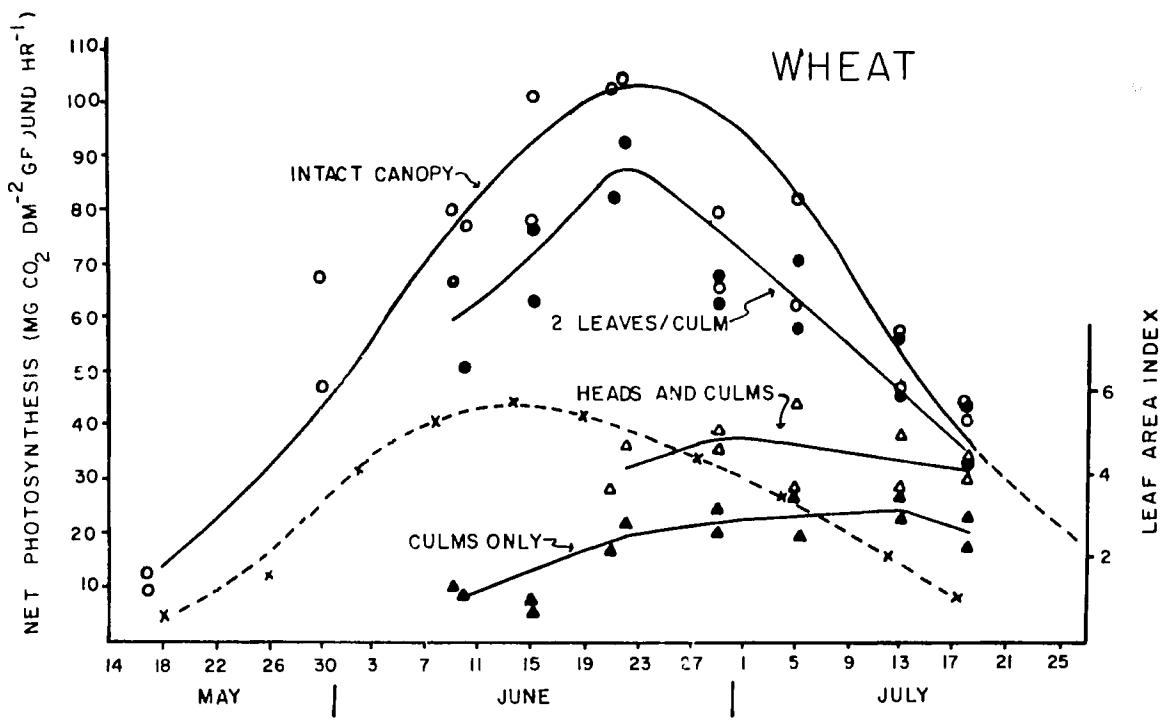

Figure 1. Wheat crop canopy photosynthesis and leaf area index throughout a growing season. These data of Era wheat were collected in 1972 and are typical of the patterns found in several varieties of spring wheat and barley. The open circles show the intact crop canopy. The dark circles and triangles show the photosynthesis remaining after bottom leaves, (2 leaves/culm), all leaves (heads and culms) and heads and leaves (culms only) were removed. Anthesis on this crop occurred about June 20.

At the same time that we were doing the work cited in the example above, we were studying the effect of various environmental factors on the growth and on the photosynthetic capacity of wheat and barley canopies in the field. We found a pattern of canopy photosynthesis and grain growth, repeating from year to year, as illustrated in Figure 1. The canopy photosynthetic

capacity increased with increasing leaf area, reaching a maximum approximately at anthesis, and thereafter it decreased rapidly.

When the grain was growing most rapidly the crop canopy had only 50% of its maximum photosynthetic rate! Measurements of total above ground plant dry weight of the plant and of the grain are shown together in Figure 2. If we take the slope of those lines at any point we get the growth rate at that point in time. The growth rates for the whole plant and for the grain, derived from the data in Figure 2, are shown in Figure 3. During much of the growth of grain in spring wheat in Minnesota the grain is growing at a faster rate than the net daily photosynthetic production. Obviously that can happen only if the grain is growing at the expense of other parts of the plant!

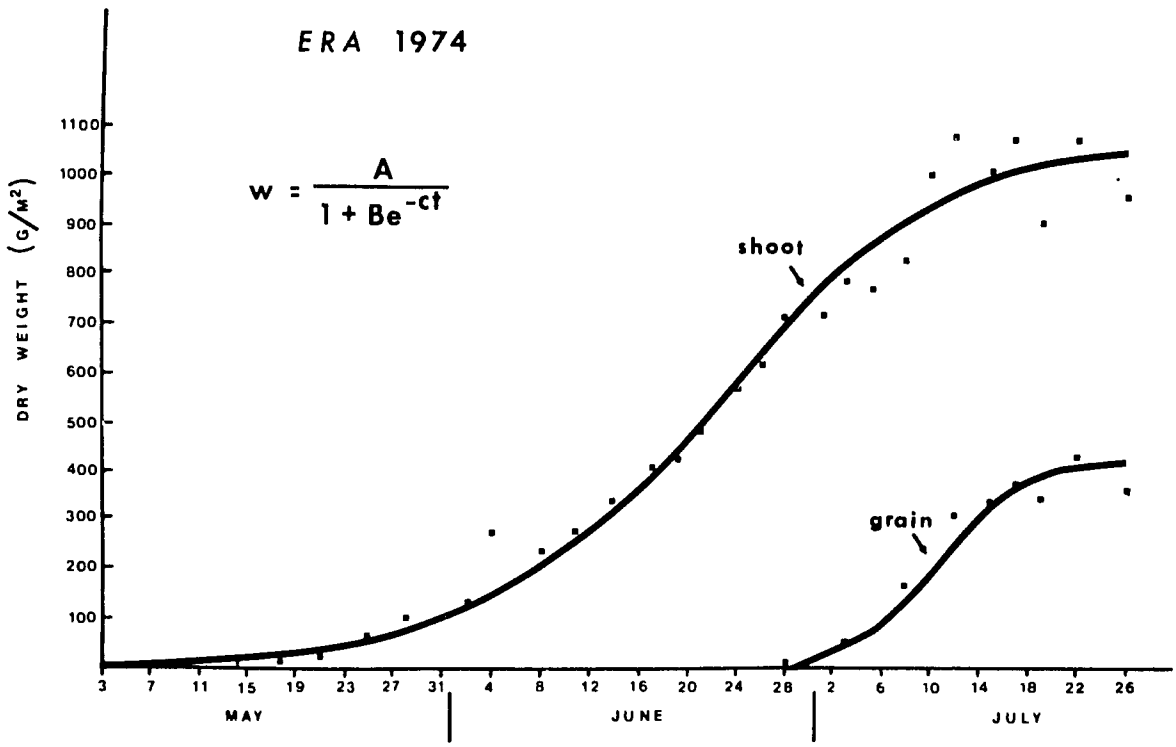

Figure 2. The pattern of dry weight accumulations in the shoot and grain for Era wheat in 1974.

What does this mean in terms of breeding higher yielding wheats? One can ask such questions as: a) Would greater photosynthesis during grain fill permit higher yields? b) Could higher yielding lines be developed if we could keep the photosynthetic factory going longer? c) Is it possible that, in our desire to develop even-ripening cultivars, we have built into the plant an undesirable senescence pattern from the standpoint of yield?

d) If temporary storage is important to yield, can we build into the plant greater temporary storage capacity? e) Could we alter the senescence pattern by using hormones?

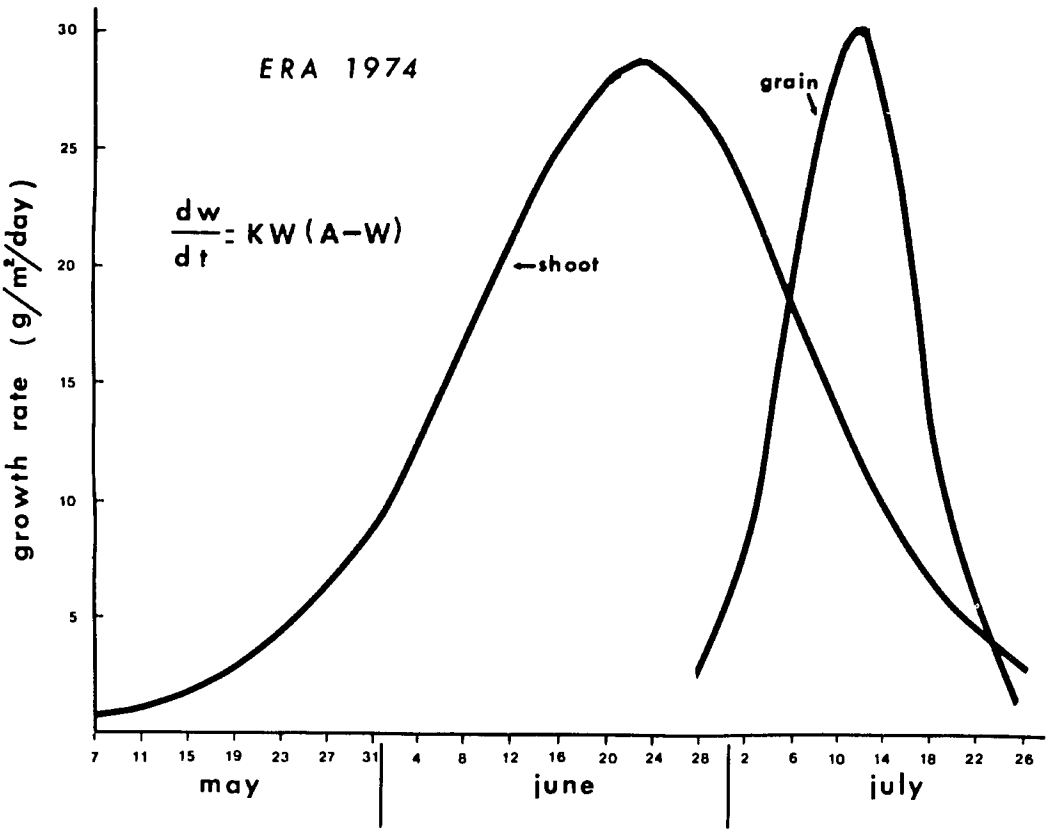

Figure 3. The growth rate of shoot and grain of Era wheat in 1974.
1 During the time that the growth rate of the grain was greater than that of the shoot, stored carbohydrates in the shoot were a major source of grain carbohydrates.

We made some small attempts to answer some of these questions. A student, Eugene Krenzer, measured the effect of CO_2 feeding in the field on two wheats--the commercial variety Era, and an experimental line we labeled 8037 which differentiated many seeds but only filled them poorly (Krenzer and Moss, 1975). The result of one of Dr. Krenzer's studies is shown in Table 1. There was a highly significant response to CO_2 during the later stages of growth of both lines but here was an especially large increase in yield (38%) in the large headed line. Thus, it appeared that more photosynthate was needed to adequately fill the kernels of large headed lines. Conversely, to take full advantage of an altered senescence pattern or an enhanced capacity for photosynthesis it may be necessary to alter the sink capacity also.

Table 1. The response of field-grown plots of a commercial, high yielding semi-dwarf spring wheat cultivar, Era, and an experimental line which has a large ear, 8037, to CO_2 feeding. The CO_2 concentration was maintained at 600 ppm during the day.

Cultivar	Vegetative	Stage of CO_2 Feeding: Floral Development	Grain Filling
		Yield - % of control	
Era	106	115*	115**
8037	103	118*	138**

(Adapted from Kenzer and Moss, 1975. *,** equal significant at the 5% and 1% level of probability.)

Another study we did was to try to manipulate the senescence rate by manipulating the environment. By growing plants in nutrient solution and keeping the temperature in growth chambers below 20°C, we could get ripe grain on still-green plants (unpublished data). We were not successful in finding a chemical or combination of application methods which had any effect on plants grown in the field.

I will now attempt to evaluate these particular experiences as they relate to the topic at hand -- the role of physiology in plant breeding.

The major difficulty for the physiologist as well as the plant breeder is that we do not know what limits yield of wheat. Much evidence suggests particular factors for specific environments; perhaps rapid progress in breeding can be made if useful genetic diversity can be found for those factors for which we have confidence in the degree to which they are limiting. It must remain a major goal of cooperative research efforts in the future, however, to define more adequately which factors are limiting yield. This goal will surely be reached more quickly if both plant breeder/geneticists and crop physiologists are working together to unravel the secrets of the wheat plant. Breeding done without a knowledge of the physiology of critical plant systems is largely a process of trial and error; physiology studied in the absence of an understanding of the controlling genetic system will most probably be misinterpreted.

If, in the future, we are successful in assembling physiologist/breeder teams to work on understanding the physiology and genetics of yield, will their progress be rapid? Perhaps not. It may take years of clever experimentation to unravel the complexity of yield and begin to approach the limit of yield of which wheat is capable.

How can anyone justify years of sustained research on a subject that has not shown any economic advantage during that period of time? We can probably all agree that the researcher and his administrators must have solid reasons, if such effort is to be justified, in accounting for use of resources; and, how many such efforts (i.e., how many traits) can be carried simultaneously

by a research group? What is the personal risk involved to the researchers and those responsible for the programs? As one analyzes these questions, it would be easy to say that it is highly improbable that effective physiology-breeding programs will ever be involved. My personal belief is that few will be sustained by industry. Perhaps it is only in the environment of graduate education programs that any really major, sustained program of physiology-breeding research is possible. Such topics as the heritability of a particular trait or its physiology do present viable thesis research projects of limited scope, where one thesis can provide the base for another. In the academic atmosphere, where the researchers may have teaching responsibilities and graduate training functions, it is possible and, I believe, highly productive to have team research on a sustained theme. For the breeder involved, an ongoing cultivar development program may be part of the responsibility which justifies the continued existence of the plant design research. If high quality scientific publications are coming out of the program and if a cultivar development program is benefiting from the spin-off then I can see physiology-breeding research programs becoming a reality.

In one sense it matters little whether progress is slow or rapid; the work must be done in either case because the problems the crop scientist faces in the future in successfully feeding the world's people are awesome. Only truly innovative and significant advances in knowledge of how the wheat plant grows will enable us to meet that challenge.

Literature-Cited

Camargo, C.E., W. E. Kronstad, and R.J. Metzger. 1980. Parent-progeny regression estimates and associations of height level with aluminum toxicity and grain yield in wheat. Crop Science 20:355358.

Kerridge, P.C. and W.E. Kronstad. 1968. Evidence of genetic resistance to aluminum toxicity in wheat (Triticum aestivum Vill., Host). Agronomy Journal 60:710-711.

Krenzer, E.G. and Dale N. Moss. 1975. Carbon dioxide enrichment effects upon yield and yield components in wheat. Crop Science 15:71-74.

Menz, Kenneth M., Dale N. Moss, Robert Q. Cannell, and William A. Brun. 1969. Screening for photosynthetic efficiency. Crop Science 9:692-694.

FRICTIONAL RESISTANCE TO WATER TRANSPORT IN WHEAT PLANTS

P. Ruckenbauer and H. Richter
Austria

Abstract

Comparisons of frictional potential losses during water transport in different plant species reveals the curious fact that resistances to water transport are as high in small herbs as in towering trees. For wheat, the problem should be solved as to whether these resistances are distributed evenly or confined to certain sections of the pathway. Spring and durum wheat plants of different varieties, water-cultured under controlled conditions, were tested under various stress climates and their water potential at different stages of development determined on leaves and whole shoots with the pressure chamber technique.

The results demonstrated, independently from the different treatments or varieties tested, large resistances within the plants between the stem bundles and the leaf blades which are responsible for a great proportion of the water-potential drop in the plant body. The implications of these results for wheat cultivation and wheat breeding are discussed.

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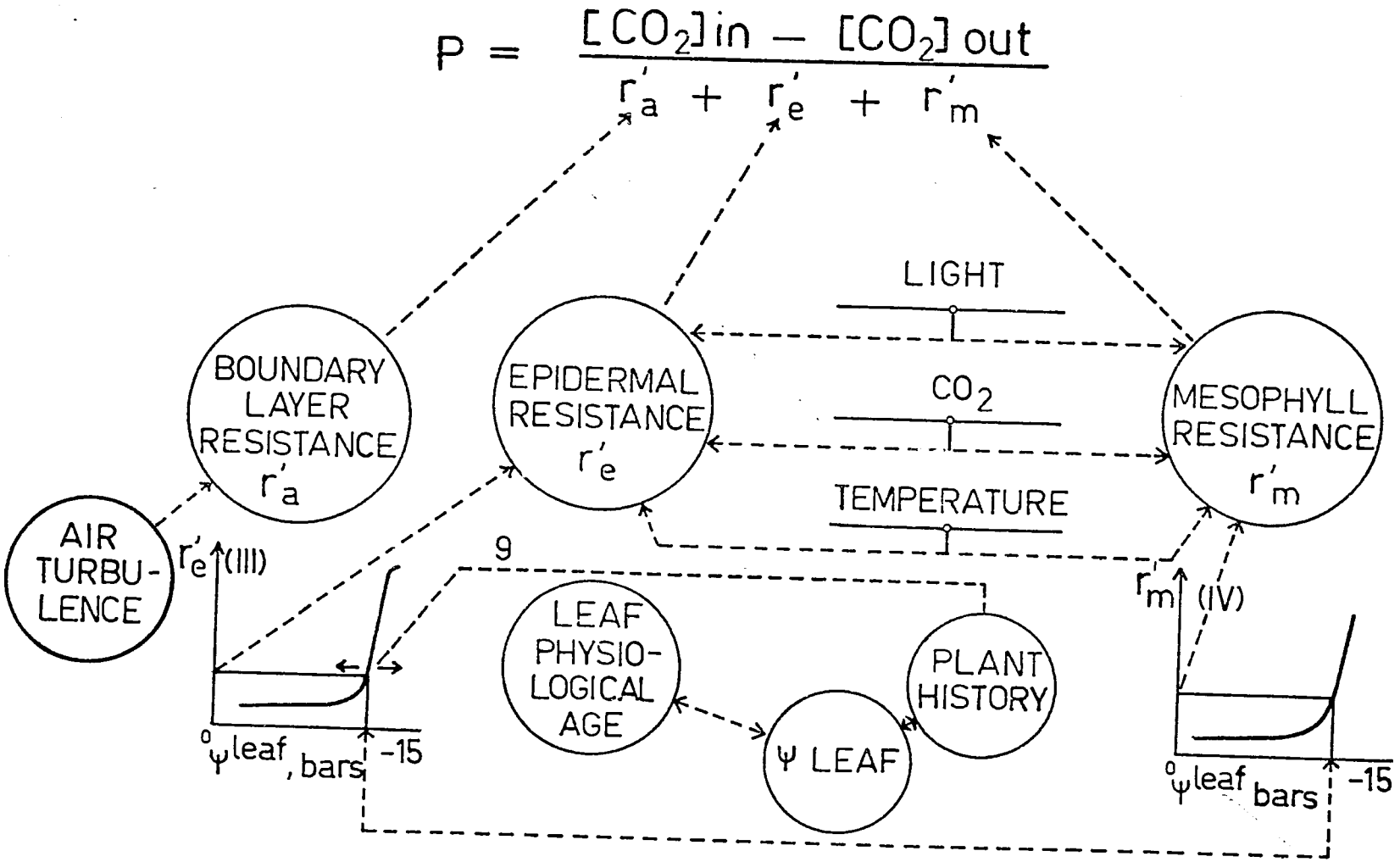
Crop performance and yield are the results of genotypic expression as modulated by continuous interactions with the environment. One of the most limiting environmental factors for crop production on a global basis is water. A better understanding of how long-term growth and yield are affected by water stress should aid in improving not only irrigation efficiency and practice, but also in developing new crop idiotypes for more efficient water use.

The central issue of plant production is the cumulative net assimilation of CO_2 and the partition of assimilates. Photosynthesis is directly influenced by a number of variables, such as boundary layer resistance (r_a'), epidermal resistance (r_e') and mesophyll resistance (r_m') via CO_2-uptake and CO_2-fixation. The link between water and CO_2-regimes is given by water status in the leaf and all its parameters depending on physiological age and plant history (Hsiao et. al., 1976). Under severe water stress, total water potential ψ_t drops below the threshold level for stomatal closure, leading to reduced CO_2-assimilation by increasing the epidermal resistance and frequently an independent increase in the leaf "mesophyll" resistance as shown in Figure 1.

Since optimal water supply as a production factor for cereals becomes more and more critical for high yielding varieties, our interests must concentrate on investigations of the water status of the wheat plant. Generally, the water status at a given point in

University of Agriculture, Vienna.



WATER POTENTIAL Ψ AND PHOTOSYNTHESIS (after HSIAO et al., 1976)

Figure 1. The relationship between water potential ψ and photosynthesis (after Hsiao et. al., 1976).

any plant body is the result of environmental and plant factors acting in the soil-plant-atmosphere continuum. In a steady state situation, these continuum demand may be split into three components $\psi_t = \psi_s + \psi_g + \psi_f$ where ψ_t total water potential, ψ_s static substrate water potential, ψ_g gravitational potential, and ψ_f frictional potential.

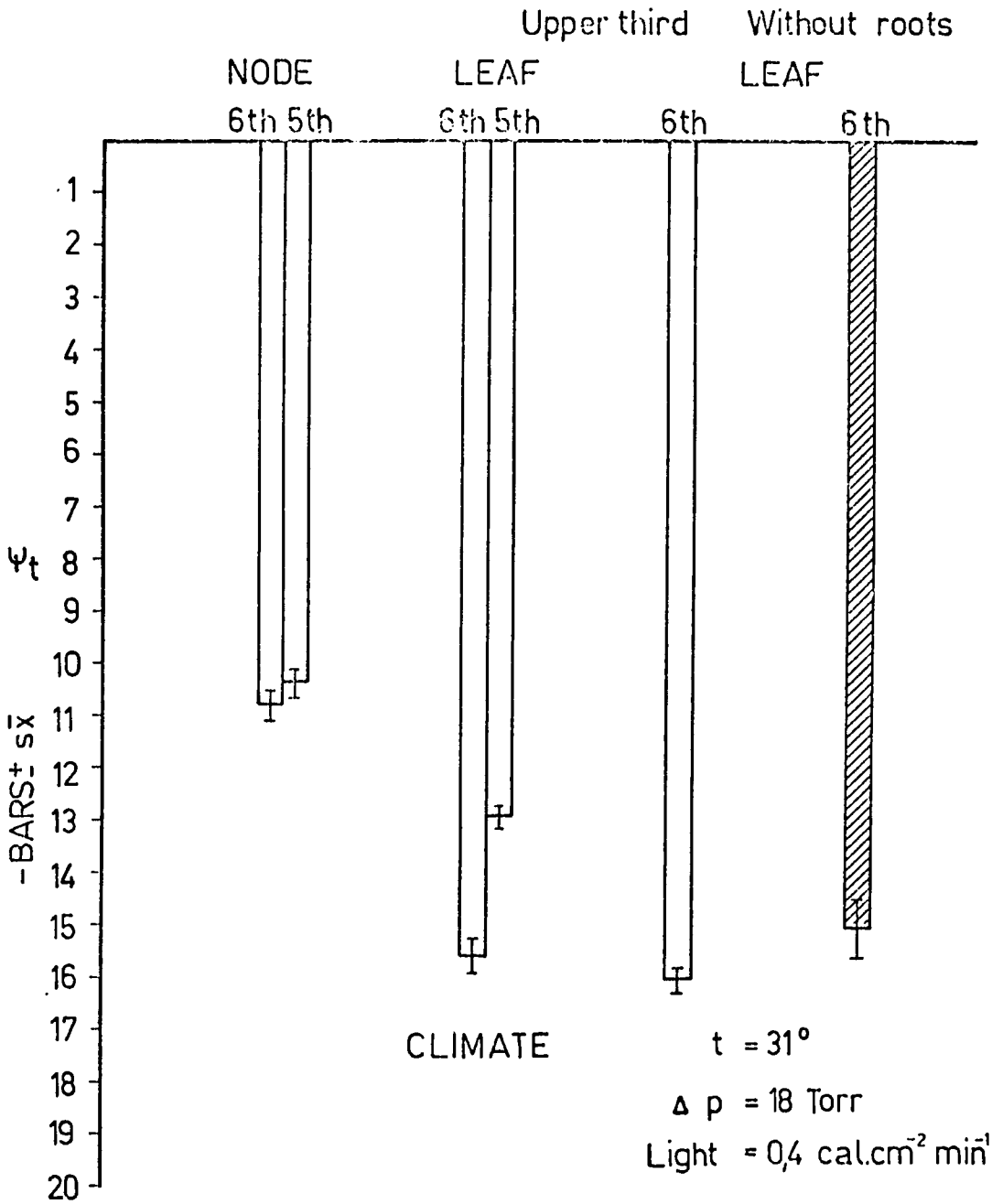
In herbaceous plants at mesic sites, ψ_s and ψ_g are close to zero, it is only the frictional potential loss which lowers total water potential during the day. A comparison of frictional potential losses during water transport in the bodies of different plant species reveals a curious fact: overall resistances seem to be as high in small herbs as in towering trees (Hellkvist et.al., 1974). This is a matter of considerable interest and it was desirable to localize these high resistances in the body of the wheat plant. Earlier experiments (Begg and Turner, 1970; Meiri et. al., 1975) indicate a high resistance between axes and leaves in dicotyledons. For monocotyledons, Denmead and Miller (1976) provided a detailed study of water transport in the wheat plant and they could separate flow resistances in the root from those in stems and leaves. The question remained whether these resistances are distributed evenly or confined to certain sections of the stem-leaf pathway and if age or history of the plant play important roles in that respect.

Material and Methods

For our 3 trial series we used spring and durum wheat varieties, grown either in a culture solution or in Mitscherlich pots in soil to control 2 different water regimes constantly during plant development. The plants were kept in a partly climatized glasshouse up to flowering stage and/or the grain filling period. Several hours before the experiment, the trays or the then fully watered pots were transported to a growth chamber lighted with xenon lamps, and a stress climate of 31° C and 18 Torr vapor pressure deficit was employed. Water potentials ψ_t were determined on leaves and culms with the pressure chamber technique (Scholander et. al., 1965, Ritchie and Hinckley 1975).

Results

In the first trial series with plants grown in water culture, we could exclude frictional tensions in the soil and, in some plants, also the root resistance. In Fig. 2, one can see an appreciable difference between measurements on culms and leaves. Leaf water potentials are always more negative and, moreover, the difference between leaves no. 5 and 6 is statistically highly significant ($P < 0.001$), whereas the small difference between the corresponding nodes is not. The climate chosen for our experiment on the variety Solo leads to values of about -13 bar in the fifth and about -16 bar in the sixth leaf. The pathway from the high potential nutrient solution to the leaf must, therefore, contain resistances responsible for major frictional potential losses. When we removed the root system, the water potential of the 6th leaf blade did not show any difference to the rooted controls.



WATER POTENTIAL IN CULMS AND ADJACENT LEAVES OF SPRING WHEAT cv SOLO IN WATER CULTURE.

Figure 2. Water potential in culms and adjacent leaves of spring wheat cv. Solo in water culture.

This may be due to the special conditions of a culture solution, under field conditions a root resistance would certainly be present, as shown in a number of experiments (Greacen et. al., 1976).

A further search for the location of the resistances by investigating the gradients within the 6th leaves did lead to only a small difference. It would thus seem that the leaf blade was not the site of the predominant potential drop in our experiments.

Therefore, a second, independent approach was tried: transpirational water losses were restricted by means of a mechanical antitranspirant. Leaves were covered with a thin layer of petrolatum jelly; a non-transpiring leaf should then adjust its potential to that of the culm at the point of departure between leaf-trace bundles and stem bundles. Yet, our method could not prevent transpiration completely, as shown in Fig. 3, but the effect was enough to raise the total water potential in treated leaves to a uniform level of about -8.5 bars, whereas their freely transpiring neighbors on the same plant are affected only slightly, if at all. Results with such a treatment corroborate, therefore, those of the stem-node measurements: resistances between two adjacent nodes are small.

The predominant result of this experiment seems to be a large resistance between culm bundles and the leaf blade, which provides for nearly half the potential drop in the body of the wheat plant. In the light of anatomical data of the nodal regions of cereals and grasses, a large hydraulic resistance causing a steep potential drop between culm and leaf of a transpiring plant is not surprising.

Frictional potential drops in the plant body are the product of partial fluxes (f) and partial resistances (r) along the branched conduit from the substrate to the leaf:

$$\psi_f = \Sigma_s^p f_i . r_i$$

Differences in these potential drops may be caused by the history of the individual plant. In the next figure (4) we can show that indeed cultivation in dry soils leads to significantly lower potentials when plants are fully watered and allowed to transpire freely. Moreover, there are differences between varieties and species. The more drought resistant durum variety Pandur reached far lower potential values than the spring variety Solo. Reports on stomatal behaviour in cereals are somewhat contradictory, and our results seem to indicate that at least part of the potential drop is due to increased frictional resistances, since under optimal light conditions and at a low vapor pressure deficit there are already significant differences between treatments. An increased friction in previously drought-stressed plants would not be surprising: anatomical features like diameters and length of vessels and tracheids are influenced by the water potentials prevailing during the differentiation period.

Frictional potential drops put a demand on the osmotic system of the leaf. It has been shown in a number of studies that frequently the closure of stomata may be induced by such potential drops, since the stomata of many species show a pronounced closing reaction when the turgor potential approximates a value of zero.

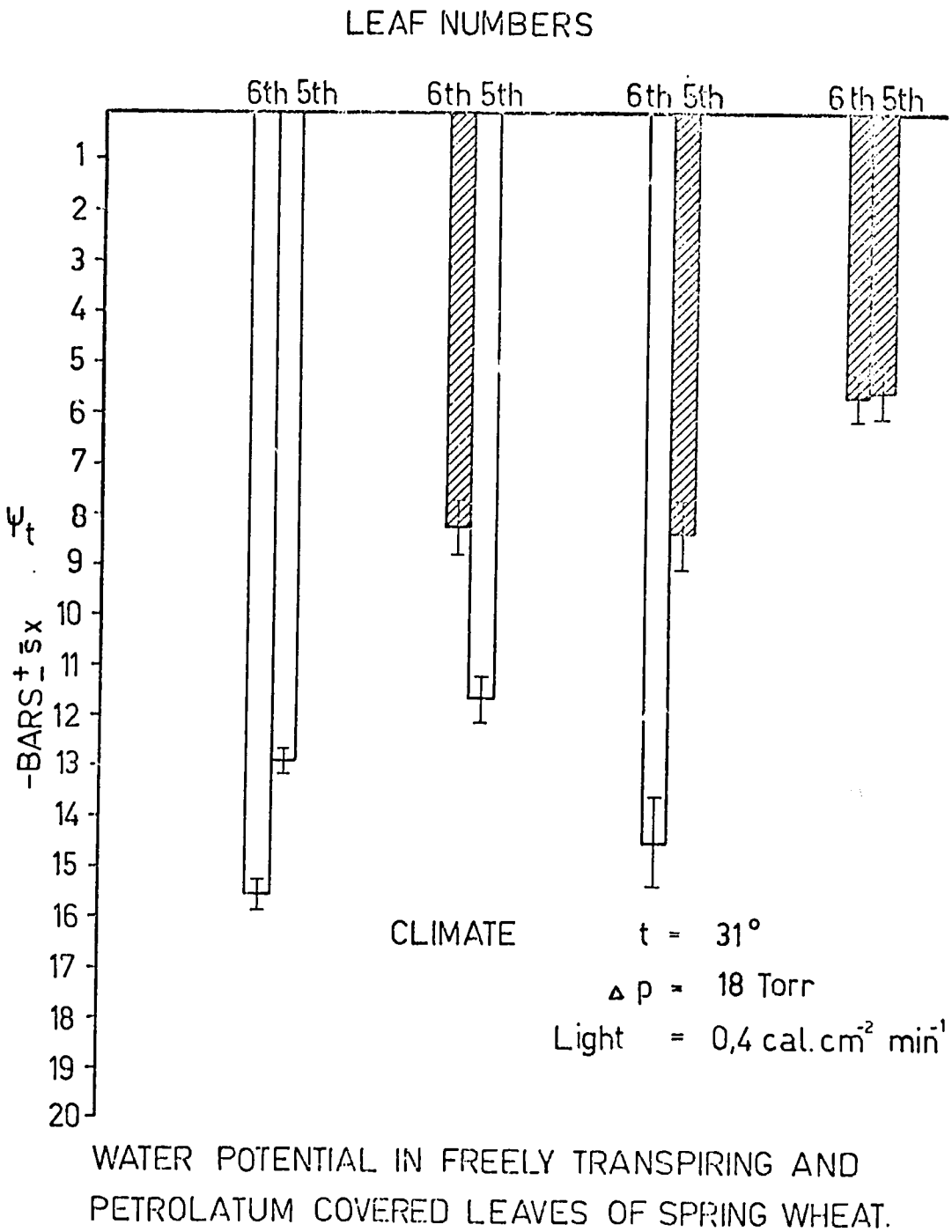


Figure 3. Water potential of the 5th and the 6th leaves in freely transpiring and petrolatum covered leaves of the spring wheat variety Solo.

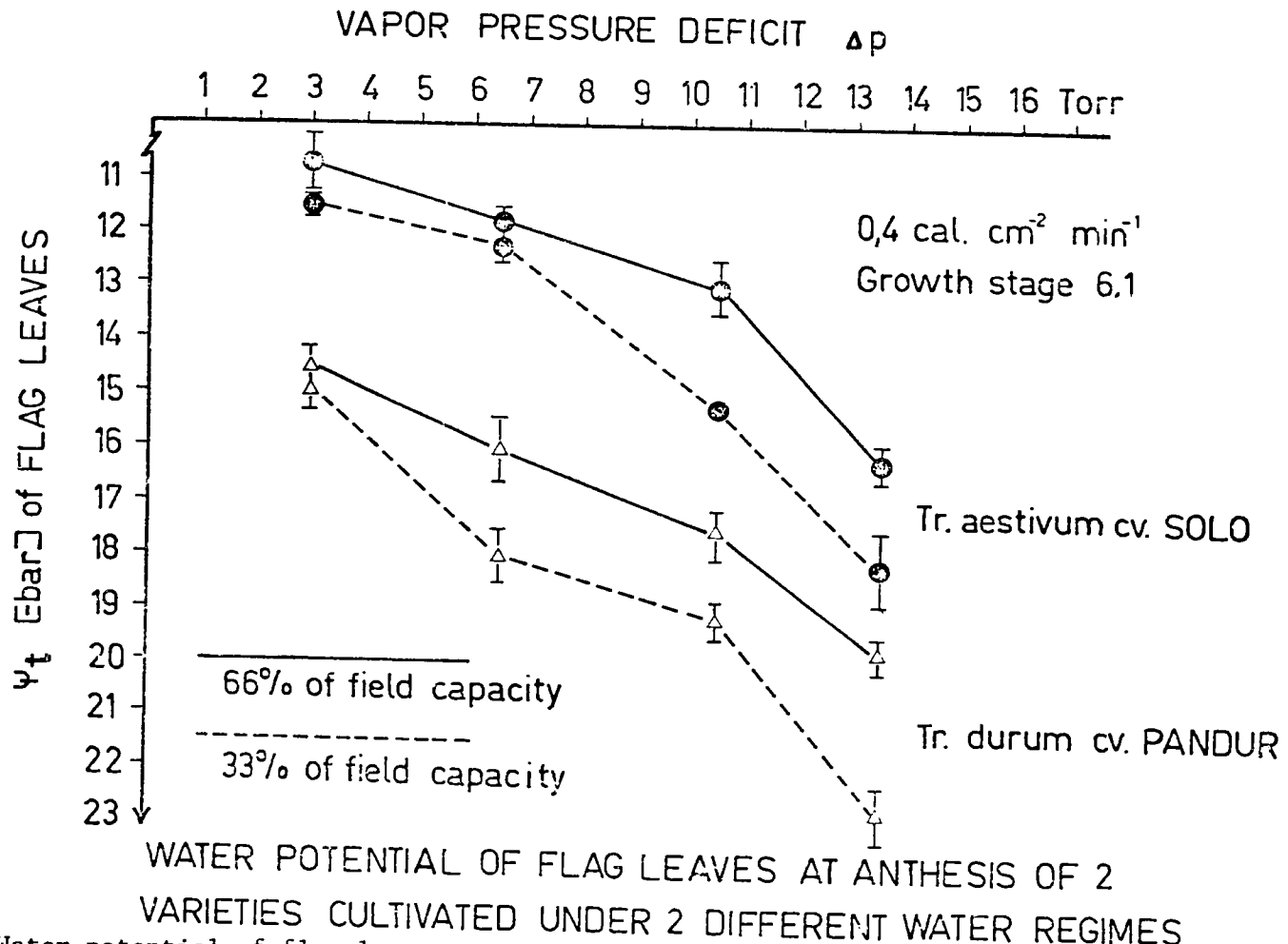


Figure 4. Water potential of flag leaves at anthesis of 2 varieties (spring wheat cv. Solo and durum wheat cv. Probstdorfer Pandur) cultivated under 2 different water regimes.

Turgor potential, ψ_p, is linked to total water potential, ψ_t, via the simple equation $(-)\ \psi_t = (-)\psi_o + (+)\psi_p$

That is to say that a lower osmotic potential, ψ_o, would permit a lower total water potential to be reached before the leaves become flaccid and before the stomata close.

The question is now: are there differences between breeding strains or varieties and between treatments, regarding the osmotic potential, that is the concentration of solutes in the cell sap? Of course, such a comparison must be made on strictly comparable material, that is on leaves with a uniform water content. In the third series of experiments, such osmotic values of plants grown in extremely dry and in optimally watered soil were compared. Leaves of two different varieties, which showed contrasting behaviour in the field under the drought conditions of 1979 in Austria were detached, fully saturated for 24 hours at 4° C in the dark and then the osmotic potential of the press sap determined by a thermocouple psychrometer technique. The diagram in Fig. 5 shows the values of the osmotic potentials of the two durum varieties which were grown in dry and well-watered soils. The drought resistant Grandur shows a far more pronounced response to drought during the whole course of development stages most critical in respect to water supply. At anthesis osmotic potentials in fully saturated leaf cells are more than 2 bars lower in drought-stressed Grandur compared with only 0.5 bar for the more mesic control variety Dwarf 73/333. It should be emphasized that these differences will become even more pronounced numerically during transpiration of the plants, when a decline in relative water content leads to a concentration of the solutes in the cell sap.

Summary

Frictional potential drops in the wheat plant occur during water transport through the soil and the plant body. An important part of the resistances in the plant body is obviously located in "constriction zones", the transition between culm and leaf bundles being especially important. Potential drops in the plant body under a given set of climatic conditions are modified by plant history: they become more pronounced after plants have been raised under dry conditions. This may be partly due to anatomical reactions. An adaptive response of the osmotic system of the leaves would help in maintaining favorable turgor relations despite the strain imposed by soil drought and increased friction in the continuum. Indeed such a reaction occurs: the osmotic potentials of fully saturated leaves become more negative when plants are cultivated in dry soil. It seems that wheat varieties differ remarkably in the degree of adaptive potential shifts. These facts should be taken more into consideration when screening breeding material for drought resistance.

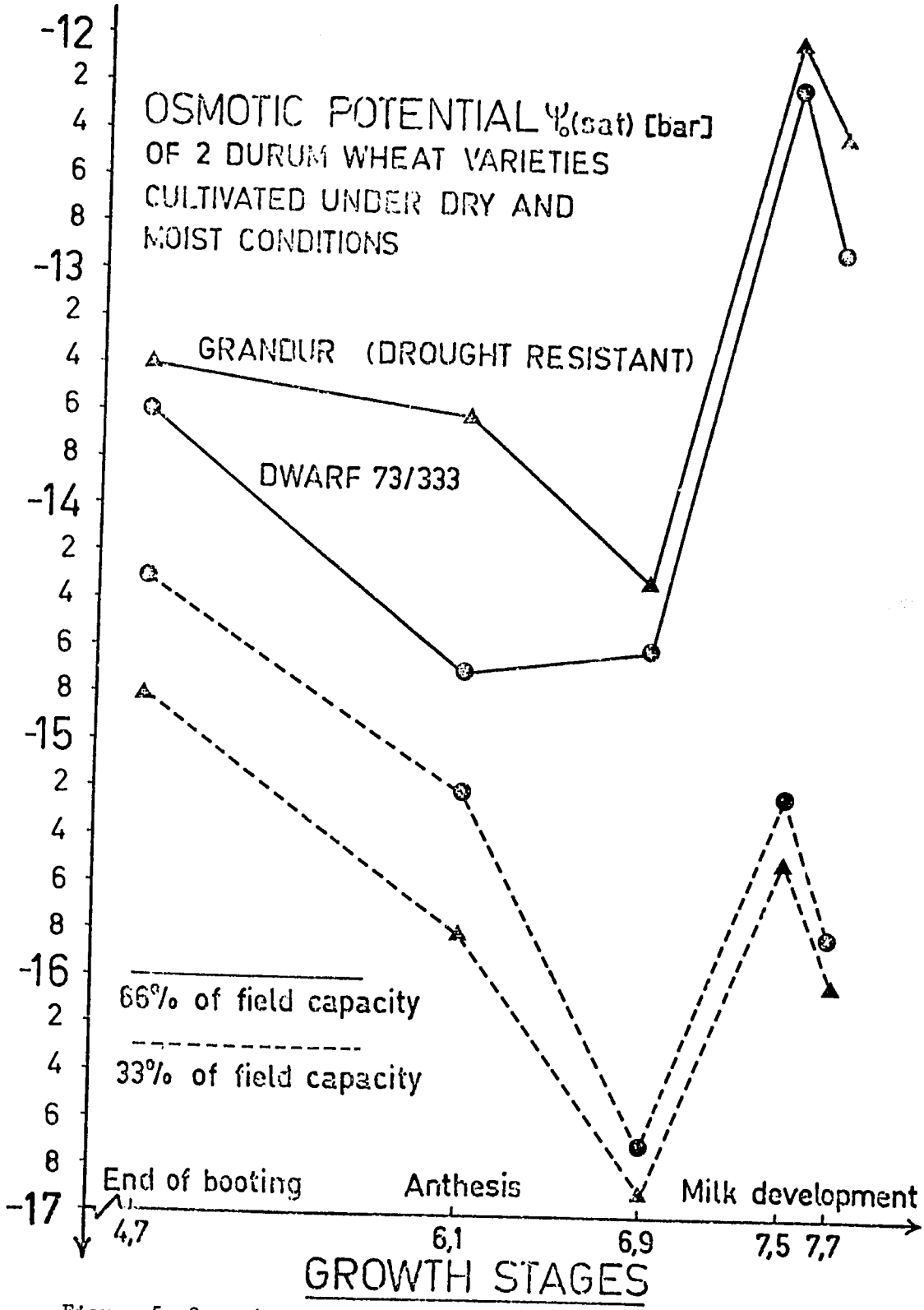


Figure 5. Osmotic potential ψ_o of 2 durum wheat varieties cultivated under dry and moist conditions measured with the thermocouple psychrometer technique.

References

Begg, J. E. and N. C. Turner. 1970. Water potential gradients in field tobacco. Plant. Physiol. 46:343-346.

Denmead, O. T. and B. D. Millar. 1976. Water transport in wheat plants in the field. Agron. J. 68:297-303.

Greacen, E. L., P. Ponsana and K. P. Barley. 1976. Resistance to water flow in the root of cereals. In: O. L. Lange, L. Kappen, E. D. Schulze (Eds.) Water and Plant Life - Problems and Modern Approaches. p. 85-100. Springer, Berlin-Heidelberg-New York.

Hellkvist, J., G. P. Richards and P. G. Jarvis. 1974. Verical gradients of water potential and tissue water relations in Sitka spruce trees measured with the pressure chamber. J. Appl. Ecol. 11:637-668.

Hsiao, T. C., E. Fereres, E. Acevedo and D. W. Henderson. 1976. Water stress and dynamics of growth and yield in crop plants. In: O. L. Lange, L. Kappen, E. D. Schulze (Eds.). Water and Plant Life - Problems and Modern Approaches, p. 281-305.

Meiri, A., Z. Plaut and A. Shimsi. 1975. The use of the pressure chamber technique for measurements of the water potential of transpiring plant organs. Physiol. Plant. 35:72-76.

Ritchie, G. A. and T. M. Hinckley. 1975. The pressure chamber as an instrument for ecological research. Adv. Ecol. Res. 9:165-254.

Scholander, P. F., H. T. Hammel, E. D. Bradstreet and E. A. Hemmingsen. 1965. Sap pressure in vascular plants. Science 148:339-346.

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EFFECTS OF NITROGEN AND WATER SUPPLY ON GROWTH AND GRAIN YIELD OF WHEAT

J. H. J. Spiertz and H. van Keulen
The Netherlands

Summary

Factors and processes limiting grain yield of wheat are discussed with emphasis on nitrogen and water use. Assimilate supply and storage capacity are interrelated before and after anthesis. During ear development an ample assimilate supply enhances the number of grains to be set; the ratio between grain number and dry matter yield at anthesis ranges from 7 to 20 grains per g dry weight. A better understanding of the environmental and genetic factors, that limit floret development and grain setting is required. An improved water and nitrogen supply favor grain yield mainly by an increase of grain number. Under temperature conditions 18-20,000 grains per m^2 are required to achieve maximum grain yields.

Grain filling at low yield levels is largely assumed by the carbohydrate and nitrogen reserves in the vegetative parts of the plant. With high growth rates of the grains, reserves deplete very fast and current photosynthesis may decrease. It is concluded that post-anthesis nitrogen uptake by the crop is a prerequisite for achieving high grain yields (>6000 kg ha^{-1}). Assimilate supply depends strongly on the water supply and water use of the crop. It is argued that under water-limited conditions CO_2 induced stomatal regulation is a desirable trait. Theoretical calculations show that the transpiration coefficient ranges between 125 and 150 kg water per kg dry matter with stomatal regulation and between 175 and 200 without this regulation mechanism.

Introduction

Growth and yield of a wheat crop is the result of the interactive response of the plants to weather and soil factors. That response may be modified by the occurrence of pests, diseases and weeds. Assuming optimal crop protection, crop growth is governed by environmental conditions and availability of water and nutrients. The main tools to overcome limitations due to weather factors are: selecting plants which are better adapted to the environment; avoidance of periods with stress-conditions; and, manipulating the environment by management practices, such as irrigation. For semi-arid conditions water supply is considered a major limiting factor to plant productivity. The grain yield of dryland crops is the result of the factors available soil water, dry matter production per unit of water use, and the partitioning efficiency to the grain (Fischer and Turner, 1978). The annual dry matter production ranges from 2,500 to 10,000 kg/ha and the harvest-index from 0.25 to 0.40. This implies not only a low yield level, but also poor

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yield stability due to variations from year to year in available soil water.

However, even under irrigation, grain and total dry matter yields of wheat grown in semi-arid areas do not exceed those in temperate climatic areas. Under temperate conditions dry matter production ranges from 12 to 20 tons/ha and the harvest-index from 0.35 to 0.50 (Spiertz, 1980). Under favorable growing conditions grain yield appears to depend more on the storage capacity than on assimilate supply. Partitioning of dry matter in the wheat plant depends on the distribution pattern before and after anthesis and on the relocation of carbohydrate and nutrient reserves from the vegetative parts to the grains.

In this paper factors and processes limiting grain yield will be discussed with emphasis on nitrogen and water use.

Assimilate supply and storage capacity.--Potential grain yields of wheat have often been calculated from the photosynthetic potentials (Evans, 1970; Sibma, 1977). However, grain yields depend also strongly on the storage capacity of the ear (Fischer and Hille Ris Lambers, 1978; Gallagher and Biscoe, 1978) and, as a consequence, on dry matter distribution (Donald and Hamblin, 1976). Generally, grain yield is more restricted by grain number than by grain weight (Figure 1). Grain weight often decreases with a rise in grain number, even at a higher yield level, due to mutual competition between grains for assimilates. However, in field experiments with split dressings of nitrogen and adequate disease control it was found that a top dressing at the boot stage raised both the number of grains per m^2 and the grain weight (Spiertz and Ellen, 1978; Spiertz, 1980). Hence, assimilate supply was enhanced to a greater extent by late nitrogen applications than by storage capacity. Under temperate growing conditions at least 18-20,000 grains per m^2 are required to achieve maximum grain yields (Darwinkel, 1978; Spiertz, 1978).

The factors limiting floret development and grain setting are incompletely understood. However, there is experimental evidence for a positive interrelation between factors promoting photosynthesis during ear development and number of grains per unit land area (Fischer, 1975; Evans, 1978; Gallagher, 1979).

A close association between number of grains (N_g) per m^2 and total above-ground dry matter yield at final harvest (DW_H) could be derived from data of a field experiment with split dressings of nitrogen (Ellen and Spiertz, 1980). This association can be represented by the following equation: $N_g = 12.4\ DW_H + 0.27$ ($R^2 = 0.88$). Assuming that dry matter yield at anthesis corresponds with straw yield at final harvest, the ratio between grain number and dry matter yield at anthesis amounts to about 20 grains per gram dry weight. This relationship differs strongly from the equations reported by Fisher (1979): 1) for irrigated crops of Yecora '70

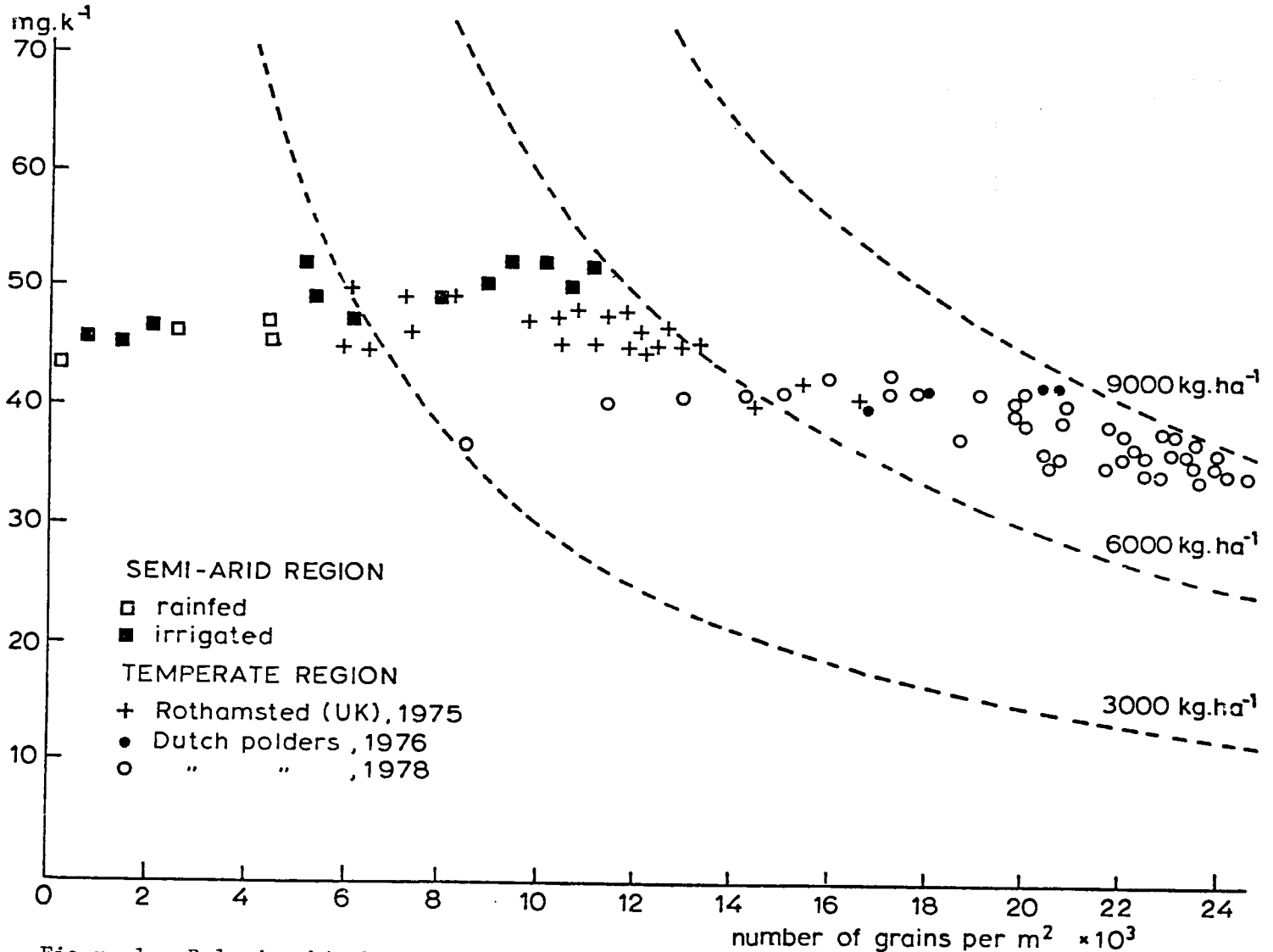

Figure 1. Relationship between level of grain yield and the variation in grain weight and grain number.

in Mexico involving several sites and sowing dates (n = 31): N_g = 13 $DW_{anthesis}$ + 4000 (R^2 = 0.35); 2) for unstressed crops of the tall Australian cultivar Heron: N_g = 7 $DW_{anthesis}$ + 2360 (R^2 = 0.83). Equation 1 holds for a $DW_{anthesis}$ range from 620 to 1078 $g.m.^{-2}$. Below 600 $g.m.^{-2}$ Fischer assumes a ratio of 20 grains per gram dry weight at anthesis. This figure fits better with our results and the relationships which can be derived from Rothamsted experiments (Pearman et al., 1977 and 1978); with spring wheat, tall and short winter wheat types 20, 14 and 20 grains per gram $DW_{anthesis}$, respectively.

Differences in the ratio between grain number and dry weight at anthesis might be explained by the rate of net photosynthesis per unit degree-day. This parameter reflects the availability of assimilates for growth in plants with a different rate of development. Photosynthesis is only slightly influenced by temperature, but development is strongly affected. Higher temperatures shorten the period from ear initiation to anthesis, thus, reducing supply of photosynthate to the ear relative to the rate of development (Rawson and Bagga, 1979).

Genetic differences between cultivars in dry matter distribution to the ear may play also, an important role. Generally, modern semi-dwarf cultivars produce more grains per unit dry weight than older long straw cultivars (Davidson and Birch, 1978; Fisher, 1979; Figure 2). This feature contributes to a more favorable dry matter distribution after anthesis. These findings support the hypothesis that assimilate supply is a major determinant of grain development in the ear. Nevertheless, other processes like cytokinine release resulting from additional root growth promoted by late nitrogen applications, could also play a role in grain formation.

It may be concluded, that environmental and management influences promoting assimilate supplies to the ear during the pre-anthesis period, enchance grain number per unit dry weight. Possible management tools for the farmer are sowing date and rate, split dressings of nitrogen and prevention of water stress (Khalifa et al., 1977; Musick and Dusek, 1980).

Importance of the carbohydrate and nitrogen economy for rate and duration of grain growth.--The major processes involved in grain filling are carbohydrate and nitrogen use. Carbohydrates may be derived from current photosynthesis and from stem reserves. Nitrogenous compounds for grain growth are mainly supplied by the vegetative parts and only to a smaller extent from post-anthesis uptake (Spiertz, 1978). At final harvest about 0.75 of the total above-ground nitrogen yield is located in the grains. Thus, the harvest-index for nitrogen is considerable higher than for dry matter; the latter ranges from 0.35 to 0.50.

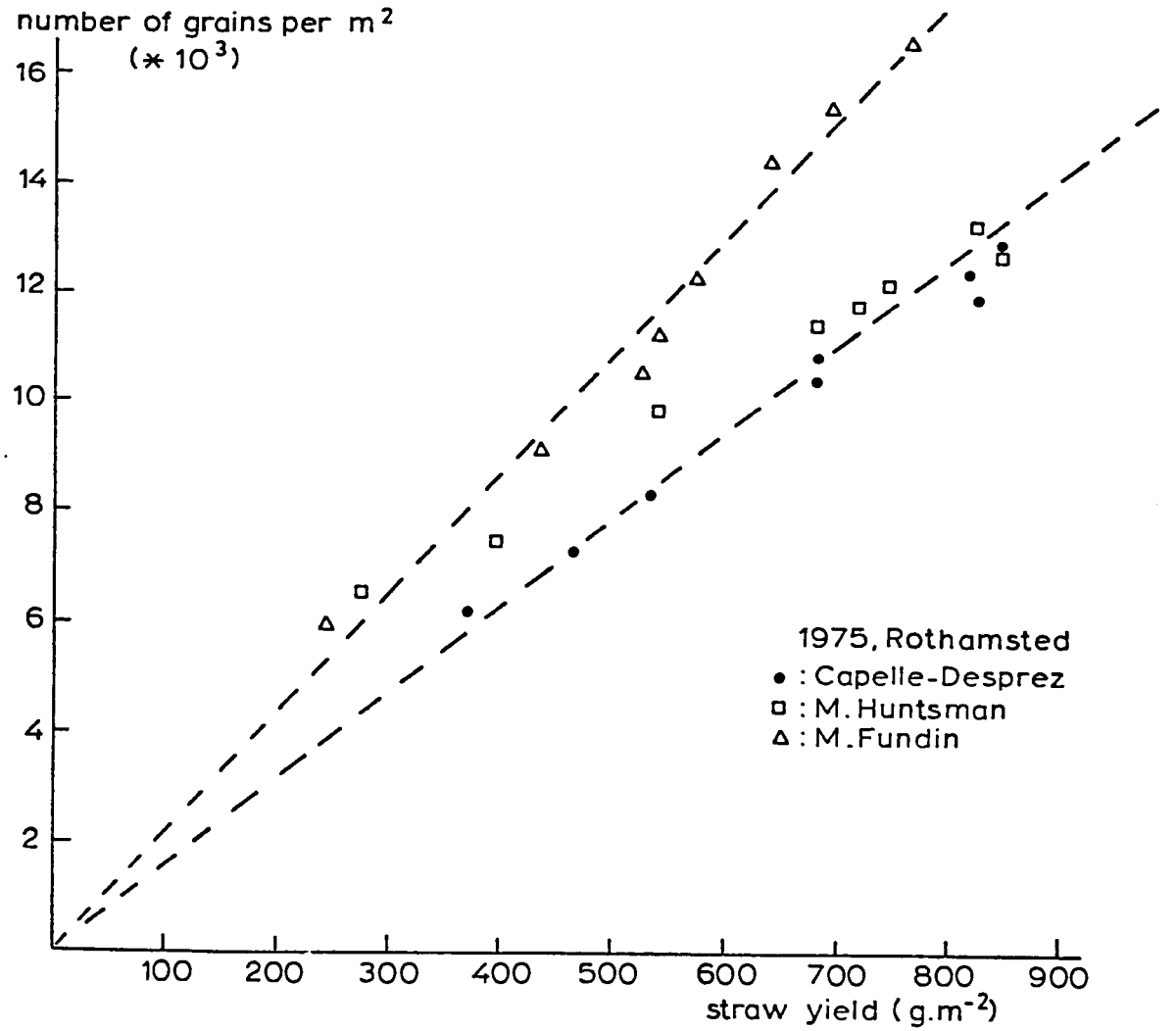

Figure 2. Relationship between grain number and dry matter yield of vegetative parts.

Carbohydrate supply to the grains is mainly supported by current photosynthesis and only for a smaller part (10-20%) by relocation of stored stem reserves (Austin et al., 1977). Water and nitrogen stress during grain filling affect mainly current assimilation through reductions in both photosynthetic area and activity (Fischer and Turner, 1978; Day et al., 1978; Spiertz and Van de Haar, 1978). The rate of assimilate accumulation by the grains is strongly governed by temperature; warmth enhances the carbohydrate and nitrogen accumulation in the grains (Sofield et al., 1977; Spiertz, 1977). However, a high rate of grain growth can only be maintained with an ample assimilate supply. Therefore, stem reserves may deplete very fast under warm growing conditions because the rate of grain growth increases and current photosynthesis may eventually decrease.

High temperatures are often associated with high evaporative demands. Under such conditions water stress not only increases the proportion of current assimilates translocated to the grains (Johnson and Moss, 1976), but also may increase the contribution from assimilates stored prior to the beginning of rapid grain growth (Fischer and Turner, 1978). Bidinger et al. (1977) found that the absolute contribution to grain yield of assimilate stored prior to anthesis was unaffected by water stress, but relative to grain yield, the contribution rose from 12% with no water deficit to 22% when there was a deficit during grain filling. The amount of mobile carbohydrates present at the end of anthesis ranges from 1500 to 3000 kg/ha (Spiertz and Ellen, 1978). Taking respiration and relocation to the roots into account the net contribution of stored carbohydrates to the grains will be restricted to values from 500 to 1500 kg/ha (De Wit et al., 1979).

Higher temperatures also increase the rate of nitrogen accumulation in the grains. Warmth during the grain filling period not only increases the nitrogen content of the grain, but it also accelerates the depletion of the nitrogen reserves in the vegetative parts of the wheat plant (Spiertz, 1977; Vos, 1980). This nitrogen depletion, especially of the leaves, might accelerate leaf senescence and thus, reduce photosynthesis towards the end of the growing season. It has been shown that late nitrogen top dressings, under dry and warm weather, but with ample water supply, appreciably increases the nitrogen content of the leaves and delays their senescence (Spiertz and Ellen, 1978). Under optimal conditions De Vos (1975) found, that the rate of crop photosynthesis remained at a high level for about 30 days after flowering, after which there was a linear decline over the next 20 days. Under conditions with moisture stress during the grain filling phase crop photosynthesis rapidly declines after flowering (Biscoe and Gallagher, 1978).

The duration of maximum grain growth may be derived from the following equation:

$$\text{Duration (D)} = \frac{\text{crop reserves (R)}}{\text{(rate of utilization by the grains (GR))} - \text{(post-anthesis rate of assimilation or supply (AR))}}$$

$$\text{D (days)} = \frac{\text{R (kg.ha}^{-1}\text{)}}{\text{GR (kg.ha}^{-1}\text{.d}^{-1}\text{)} - \text{AR (kg.ha}^{-1}\text{.d}^{-1}\text{)}}$$

Examples:

a. Duration based on optimum carbohydrate supply:

$$D_C = \frac{\text{Reserves for grain growth*}}{(CH_2O\text{-accumulation in the grains})^{+} - (\text{rate of net photosynthesis})^{o}} = \frac{1500}{200 - 150} =$$

30 days

* Reserves available for grain growth correspond to total water-soluble carbohydrates in the stem minus relocation to the roots and maintenance respiration.

\+ Rate of carbohydrate accumulation is determined by the number of grains per unit area of land and by temperatures. Rate of grain growth per day may vary between 1.0 and 2.0 mg per kernel or 100 and 300 $kg.ha^{-1}$. Growth rate per unit land area shows a wider range due to a large variation in the number of grains per m^2.

o Photosynthesis after anthesis is closely linked with leaf area duration. Under temperate conditions well fertilized and disease-free crops maintain a constant level of net photosynthesis during 3 weeks after anthesis followed by a gradual decline (De Vos, 1977). In semi-arid areas the rate of net-photosynthesis mostly drops after the start of grain-filling.

b. Duration based on optimum nitrogen supply:

$$D_N = \frac{\text{N-reserves in vegetative organs*}}{(\text{N-accumulation by the grains})^{+} - (\text{N-uptake by the crop after anthesis})^{o}} = \frac{90}{4 - 1} =$$

30 days

* Available nitrogen for relocation to the grains can be derived from nitrogen content of the crop at anthesis minus nitrogen residues in straw and chaff. The former amounts to about 150 $kg.ha^{-1}$ and the latter to about 60 $kg.ha^{-1}$ for an average wheat crop. Mobile nitrogen for relocation to the grains is contributed by the leaves (40%), the stem and leaf

sheaths (40%), and chaff (20%). Nitrogen relocation from the roots to the grains is considered as nitrogen uptake.

+ The rate of N-accumulation in the grains is determined by the DM growth rate and the N-content of the grain. For example, a growth rate of 200 $kg.ha^{-1}.d^{-1}$ and a nitrogen content of 20 $g.kg^{-1}$ results in a rate of N-accumulation of 4 $kg.ha^{-1}.d^{-1}$. A growth duration of 30 days results in a nitrogen yield of the grains of 120 $kg.ha^{-1}$. An increase in post-anthesis N-uptake to 2 $kg.N.ha^{-1}.d^{-1}$ would permit a potential duration of grain growth of $\frac{90}{4 \quad 2}$ = 45 days.

o A substantial post-anthesis N-uptake is a prerequisite for achieving high grain yields. Increased nitrogen reserves in the vegetative parts is strongly associated with the adverse effects of a too leafy wheat crop (risk of lodging and increased susceptibility to diseases). N-uptake after anthesis may account for half of the nitrogen yield of the grains when water and nitrate is ample available in the rooted layers (Spiertz and Ellen, 1978).

Nitrogen use, growth and grain yield.--The uptake of nitrogen by a wheat crop depends on the amount of available soil nitrogen and the recovery of fertilizer nitrogen. The amount of nitrogen uptake without nitrogen dressing is associated with the nitrate made available from soil organic matter (mineralization) and with rooting characteristics (root growth and activity). The relations between nitrogen dressing and uptake by the crop and the uptake-yield response curve are reproduced in Figure 3. At low values of N-uptake the relation between yield and uptake is linear with a rate of about 60 kg grains per kg accumulated N in the grain. At higher levels of uptake the yield response curve deviates from the straight curve reflecting an increase in the nitrogen content of the grains. The level of the plateau where increased N-uptake does not result in higher grain yields is determined by other limiting growth factors (e.g., water shortage, disease and pests).

The slope of the application-uptake curve, the recovery fraction of the applied fertilizer, is often lower under dry than under irrigated conditions (Campbell and Paul, 1978). Two mechanisms may be responsible for this effect. Dry conditions in the soil may render the mineral nitrogen present unavailable, since it cannot be transported to the root system. This may already be the case when only the top soil dries out where most of the mineral nitrogen is located, while moisture can still be taken up from greater depth.

Another possibility is that moisture shortage effects growth to such an extent, that nitrogen concentration in the material approaches the maximum value. Further uptake is then inhibited by physiological functioning. The two effects have been demonstrated elegantly in a series of pot experiments (Rehatta et al., 1979).

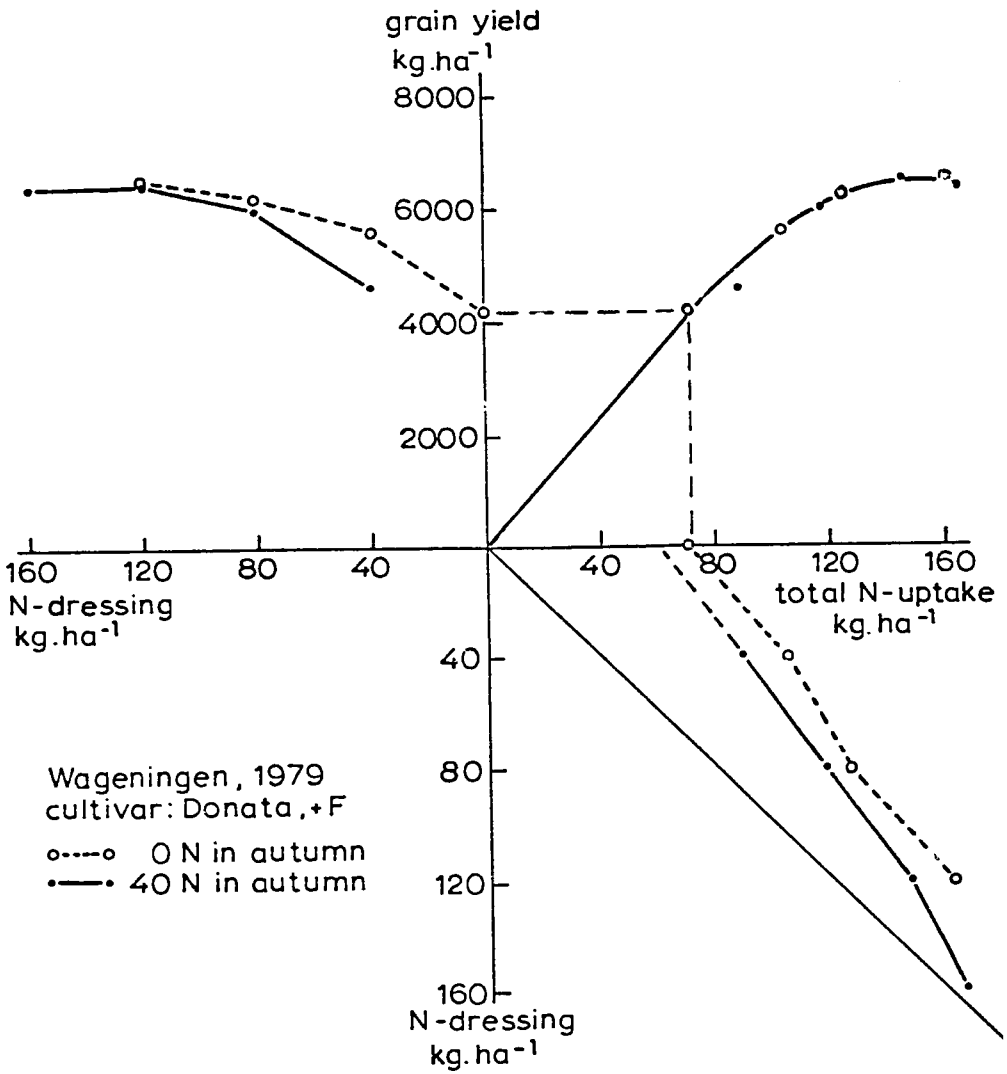

Figure 3. Relations between nitrogen dressing, uptake and utilization.

The efficiency of utilization of nitrogen by the wheat crop, defined as the amount of grain produced per unit nitrogen absorbed, is determined on the one hand by the nitrogen harvest-index and on the other hand by nitrogen concentration in the grains. The nitrogen harvest index, the proportion of the total amount of nitrogen present in the grains, usually ranges between 0.74 and 0.82 under both temperate and semi-arid conditions (Spiertz, 1978; Campbell and Paul, 1978). When, however, during the grain-filling stage water shortage develops, translocation of N from the vegetative tissue to the growing grains may be hampered, resulting in a lower nitrogen harvest-index, thus decreasing nitrogen use efficiency. This effect may become even stronger, when the moisture stress leads to accelerated senescence of the photosynthetic tissue. The developing grain cannot be properly filled so that, at harvest, kernels have a high protein content and a low dry weight, in extreme situations leading to shriveled grains. The combined effects, which are not uncommon under semi-arid conditions, may lower the nitrogen use efficiency from the above-mentioned 60 kg per kg N to values around 20-30 kg grain per kg N absorbed (Halse et al., 1969).

In phytotron experiments with regular nitrogen supply to the plants, on average about 65% of the grain nitrogen was derived from the vegetative aerial parts, the remainder originating from uptake by the roots or the soil after anthesis (Spiertz, 1978). The greatest variation was found in post-anthesis uptake; Vos (pers. comm.) found a contribution to grain nitrogen ranging from 18 to 50%, the average being 32%. In field experiments testing late nitrogen applications, the highest post-anthesis nitrogen uptake (50%) was found in the warm and bright growing season of 1976 (Spiertz and Ellen, 1978) and the lowest (20%) in crops with an early vigorous development (Spiertz and Van de Haar, 1978). These results suggest that, at least under some conditions, availability of nitrogen in the soil restricts post-anthesis uptake.

Generally, nitrogen use can be derived from predicted above-ground dry matter yield, DM- and N-harvest-index and the grain nitrogen concentration.

$$\text{Crop Nitrogen Yield} = \frac{\text{Dry Matter Yield X Harvest Index X Grain Nitrogen Content}}{\text{Nitrogen Harvest Index}}$$

<u>Example</u>:

$$\text{Crop Nitrogen Yield} = 15{,}000\ \text{kg.ha}^{-1} \times 0.45 \times 20\ \text{g N.kg}^{-1} \times \frac{1}{0.75} = 180\ \text{kg.ha}^{-1}$$

Water use, growth and grain yield.--Total above-ground dry matter yield can be predicted from: a) the amount of intercepted radiation within the growth cycle of the crop; and b) the available soil water, precipitation and water use efficiency.

The process of CO_2 assimilation inevitably leads to a loss of water from the crop to the atmosphere. Since the exchange of CO_2 and of water vapour are governed by the same physical principles, a linear relation between the two processes is expected. Since CO_2 assimilation is closely associated with dry matter production a proportionality exists between dry matter yield and the total transpirational loss of the vegetation. The value of the proportionality, defined as water use efficiency (WUE), transpiration coefficient (TRC) or more recently transpiration efficiency (TE), depends on environmental conditions, notably the evaporative demand of the atmosphere (De Wit, 1958). Doyle and Fisher (1979) found a marked seasonal variation in TE, which was associated with differences in evaporation.

The ratio between transpiration and assimilation also is strongly influenced by stomatal behavior. When stomatal aperture is governed by the CO_2 concentration inside the stomatal cavity as has been demonstrated for various plant species (Goudriaan and Van Laar, 1978), the ratio between assimilation and transpiration is around 100 kg H_2O kg^{-1} (CH_2O) under average conditions of radiation and humidity for C3-species maintaining a concentration inside the stomatal cavity of 210 mg kg^{-1}. In terms of dry matter this value then ranges between 125-150 kg H_2O kg^{-1} (dry matter) depending on the chemical composition of the plant material formed (Penning de Vries, 1974).

When, on the other hand, CO_2-induced stomatal regulation is absent, so that stomata are fully open in the light and completely closed in the dark, the transpiration coefficient under identical conditions varies between 175 and 200 kg H_2O kg^{-1} (dry matter). These values show, that under water limited conditions, CO_2-induced stomatal regulation is a desirable trait even though actual rates of CO_2-exchange (assimilation) may be lower than without regulation during periods when sufficient moisture is available (van Keulen et al., 1980).

When plants are under moisture stress, the stomatal aperture is governed by the water status of the plant irrespective of its regulating mechanism in the unstressed situation. When the stomata close, both assimilation and transpiration are affected and the internal CO_2-concentration attains values which are slightly lower than in the unstressed situation. At a given stomatal conductance the rate of CO_2-diffusion into the stomatal cavity is, therefore, somewhat higher. As a result, the assimilation/transpiration ratio is higher than under optimum moisture supply. This reasoning only holds, of course, when the mesophyll resistance and the CO_2-compensation point are not affected by the stress conditions. But even then, the values reported by Doyle and Fischer (1979) of 71

kg H_2O kg^{-1} (dry matter) equivalent with their transpiration efficiency of 140 g $m^{-2}mm^{-1}$ seems very high and is comparable to values normally found for C4-species having a much lower regulatory value for the internal CO_2-concentration.

Water stress affects grain yield most if applied during the critical period of ear formation, about two or three weeks before anthesis (Fischer, 1973). Mostly, crops are likely to experience drought after anthesis. Davidson and Birch (1978) found that efficiencies of water use after anthesis increased as water supply decreased. The differences in efficiency of water use for grain production simply reflected differences in dry matter distribution and relocation.

Generally, a positive interaction of irrigation and nitrogen fertilization on grain yield of wheat has been found (Shimshi and Kafkafi, 1978) when late irrigation was applied. From their results it can be derived that irrigation increases both grain number and grain weight, and nitrogen promotes grain number but reduces grain weight strongly without irrigation.

Day et al. (1978) found a linear relationship between grain yield of barley and water use. They concluded that potential yield can be defined based on total stored soil water plus irrigation and rainfall. Based on equal approach Van Heemst et al. (1978) calculated that under average Dutch growing conditions 200 mm available soil water is needed to compensate for the deficit between rainfall and evapotranspiration. Within a range in available soil water from 50 to 200 mm, they predicted maximum grain yields ranging from 505 to 7450 kg.ha^{-1} for winter wheat and from 4800 to 6950 kg.ha^{-1} for spring wheat. These values were derived from calculations of potential photosynthesis and a reduction factor equal to the ratio between actual and potential evapotranspiration.

References

Austin, R. B., J. A. Edrich, M. A. Ford, and R. D. Blackwell. 1977. The fate of dry matter, carbohydrates and ^{14}C lost from the leaves and stems of wheat during grain filling. Ann. Bot. 41:1309-1321.

Bidinger, F., R. B. Musgrave, and R. A. Fischer. 1977. Contribution of stored pre-anthesis assimilate to grain yield in wheat and barley. Nature (London) 270:431-433.

Biscoe, P. V. and J. N. Gallagher. 1978. A physiological analysis of cereal yield. I. Production of dry matter. Agricultural Progress. pp. 34-50.

Campbell, C. A. and E. A. Paul. 1978. Effects of fertilizer N and soil moisture on mineralization, N-recovery and A-values, under spring wheat grown in small lysimeters. Can. J. Soil Sci. 58:39-51.

Darwinkel, A. 1978. Patterns of tillering and grain production of winter wheat at a wide range of plant densities. Neth. J. Agric. Sci. 26:383-398.

Davidson, J. L. and J. W. Birch. 1978. Response of a standard Australian and a Mexician wheat to temperature and water stress. Aust. J. Agric. Res. 29:1091-1106.

Day, W., B. J. Legg, B. K. French, A. E. Johnston, D. W. Lawlor, and W. de C. Jeffers. 1978. A drought experiment using mobile shelters: the effect of drought on barley yield, water use and nutrient uptake. J. Agric. Sci., Camb. 91:599-623.

de Wit, C. T. 1958. Transpiration and crop yields. Verslagen van Landbouwkundige Onderzoekingen 64.6. 88 pp.

de Wit, C. T., H. H. van Laar, and H. van Keulen. 1979. Physiological potential of crop production. In Plant Breeding Perspectives. (Eds. J. Sneep and A. J. T. Hendriksen):47-82.

Donald, C. M. and J. Hamblin. 1976. The biological yield and harvest index of cereals as agronomic and plant breeding criteria. Adv. Agron. 28:361-405.

Doyle, A. D. and R. A. Fischer. 1979. Dry matter accumulation and water use relationship in wheat crops. Aust. J. Agric. Res. 30:815-829.

Ellen, J. and J. H. J. Spiertz. 1980. Effects of rate and timing of nitrogen dressings on grain yield formation of winter wheat (T. aestivum L.). Fertilizer Res. (in press)

El-Sharkawy, M. A., F. A. Sorour, M. I. Shaalan, and A. Al-Kaed. 1977. Effect of nitrogen level and soil moisture stress on growth, yield and yield components of "Sidi Misri I" wheat (Triticum aestivum L.). Libyan J. Agric. 6(I):69-78.

Evans, L. T. 1978. The influence of irradiance before and after anthesis on grain yield and its components in microcrops of wheat grown in a constant daylength and temperature regime. Fld. Crops Res. I:5-19.

Fischer, R. A. 1973. The effect of water stress at various stages of development on yield processes in wheat. In Plant Response to Climatic Factors. UNESCO, Paris. pp. 233-241.

Fischer, R. A. 1975. Yield potential in a dwarf spring wheat and the effect of shading. Crop Sci. 15:607-613.

Fischer, R. A. 1979. Growth and water limitation to dry land wheat yield in Australia: a physiological framework. J. Aust. Inst. Agric. Sci. 45:83-94.

Fischer, R. A. and D. Hille Ris Lambers. 1978. Effect of environment and cultivar on source limitation to grain weight in wheat. Aust. J. Agric. Res. 29:443-458.

Fischer, R. A. and N. C. Turner. 1978. Plant productivity in the arid and semi-arid zones. Ann. Rev. Plant Physiol. 29:277-317.

Gallagher, J. N. and P. V. Biscoe. 1978. Assimilate partitioning and high yield in cereals. In Proceedings British Crop Protection Council: Opportunities for Chemical Plant Growth Regulation. 21: 113-124.

Gallagher, J. N. 1979. Ear development: processes and prospects. In Crop Physiology and Cereal Breeding. Proceedings of a Eucarpia workshop, Wageningen, The Netherlands, November 14-16, 1978. (Eds. J. H. J. Spiertz and Th. Kramer):3-9.

Goudriaan, J. and H. H. van Laar. 1978. Relations between leaf resistance, CO_2 concentration and CO_2 assimilation in maize, beans, lalang grass and sunflower. Photosynthetica 12:241-249.

Halse, N. J., E. A. N. Greenwood, P. Lapins, and C. A. P. Boundy. 1969. An analysis of the effects of nitrogen deficiency on the growth and yield of a western Australian wheat crop. Aust. J. Agric. Res. 20:987-998.

Heemst, H. D. J. van, H. van Keulen, and H. Stolwijk. 1978. Potential, gross and net production of Netherlands agriculture. Agric. Res. Rep. 879, Pudoc, Wageningen. 25 pp.

Johnson, R. R. and D. N. Moss. 1976. Effect of water stress on $^{14}CO_2$ fixation and translocation in wheat during grain filling. Crop Sci. 16:697-701.

Khalifa, M. A., M. H. Akasha, and M. B. Said. 1977. Growth and N-uptake by wheat as affected by sowing date and nitrogen in irrigated semi-arid conditions. J. Agric. Sci., Camb. 89:35-42.

Musick, J. T. and D. A. Dusek. 1980. Planting date and water deficit effects on development and yield of irrigated winter wheat. Agron. J. 72:45-52.

Pearman, I., S. M. Thomas, and G. N. Thorne. 1977. Effects of nitrogen fertilizer on growth and yield of spring wheat. Ann. Bot. 41:93-108.

Pearman, I., S. M. Thomas, and G. N. Thorne. 1978. Effects of nitrogen fertilizer on the distribution of photosynthate during grain growth of spring wheat. Ann. Bot. 42:91-99.

Penman, H. L. 1948. Natural evaporation from open water, bare soil and grass. Proceedings of the Royal Society of London, A193:120-145.

Penning de Vries, F. W. T. 1974. Substrate utilization and respiration in relation to growth and maintenance in higher plants. Neth. J. Agric. Sci. 22:40-44.

Rawson, H. M. and A. K. Bagga. 1979. Influence of temperature between floral initiation and flag leaf emergence on grain number in wheat. Aust. J. Plant Physiol. 6:391-400.

Rehatta, S. B., W. Dijkshoorn, and J. E. M. Lampe. 1979. Nitrogen uptake by rice plants from a dry soil at maintained water supply from a greater depth. Neth. J. Agric. Sci. 27:99-110.

Shimshi, D. and U. Kafkafi. 1978. The effect of supplemental irrigation and nitrogen fertilization on wheat (Triticum aestivum L.). Irrigation Science 1:27-38.

Sibma, L. 1977. Maximization of arable crop yields in the Netherlands. Neth. J. Agric. Sci. 25:278-287.

Sofield, I, L. T. Evans, M. G. Cook and I. F. Wardlaw. 1977. Factors influencing the rate and duration of grain filling in wheat. Aust. J. Plant Physiol. 4:785-797.

Spiertz, J. H. J. 1977. The influence of temperature and light intensity on grain growth in relation to the carbohydrate and nitrogen economy of the wheat plant. Neth. J. Agric. Sci. 25: 182-197.

Spiertz, J. H. J. 1980. Grain production and assimilate utilization of wheat in relation to cultivar characteristics, climatic factors and nitrogen supply. Agricultural Research Reports 881, Pudoc, Wageningen. 35 pp.

Spiertz, J. H. J. 1980. Grain production of wheat in relation to nitrogen, weather and diseases. In Advances in Crop Production and Crop Protection (R. G. Hurd, P. V. Biscoe, and C. Dennis eds.). Proc. AAB-conference, Reading (U.K.) (in press)

Spiertz, J. H. J. and J. Ellen. 1978. Effects of nitrogen on crop development and grain growth of winter wheat in relation to assimilation and utilization of assimilates and nutrients. Neth. J. Agric. Sci. 26:210-231.

Spiertz, J. H. J. and H. van de Haar. 1978. Differences in grain growth, crop photosynthesis and distribution of assimilates between a semi-dwarf and a standard cultivar of winter wheat. Neth. J. Agric. Sci. 26:233-249.

Vos, J. 1980. Personal communication.

Vos, N. M. de. 1975. Field photosynthesis of winter wheat during the grain-filling phase under highly fertile conditions. Proceedings of the Second International Winter Wheat Conference, Zagreb, Yugoslavia. pp. 251-255.

Vos, N. M. de. 1977. Wheat. In Crop Photosynthesis: Methods and Compilation of Data Obtained with a Mobile Field Experiment. (Th. Alberda ed.). Agric. Res. Rep. 865:22-30.

CHEMO-VERNALIZATION OF WINTER WHEAT

Z. Barabas and I. T. Csepely
Hungary

The efficiency of breeding is obviously improved by growing several generations per year. Germinating immature seed can save a few months per generation in a winter wheat breeding program, compared to maturing and storing seed for up to 78 days (Abramova and Gurinovich 1972) until dormancy requirements are satisfied. Embryoculture was used for this purpose very early in wheat (Dietrich 1924) (Fig. 1, Fig. 2.). Germinable seed has been harvested as early as 8 to 10 days after anthesis (Nutman 1941); however, seed as immature as this has a low germination. Seed harvested 20 days after anthesis treated with H_2O_2 and at a low temperature germinated as fast and to the same extent as fully mature seed (Teich 1980). If generation time is reduced by one of these ways, nearly half the remaining time is taken up by vernalization.

The biochemical processes during vernalization have been studied intensively but not completely understood till now (Devay, 1967; Hess, 1979; Ishikawa et al., 1975; El-Antably-Hamed, 1976; Reda-Fatma, 1976 etc.). For certain winter plant species, cold treatment can be replaced by chemicals. Gibberellic acid and its derivatives proved to be one of the most effective compounds. Results were obtained by the total exclusion of cold in Hyoscyamus (Lang, 1956), Arabidopsis (Sarkar, 1958) and endive (Rapoport and Bonner, 1960). The partial replacement of cold treatment succeeded in barley (James and Lund, 1960), rye (Fruinsma and Patil, 1963) and celery (Hanisova et al., 1975) with potassium gibberellate. However, with wheat similar experiments were ineffective (Pauli et al., 1962; Devay and Barabas, 1957, unpublished).

Tomita (1963, 1964, 1968, 1977 etc.) suggested treating winter wheat seedlings with AMP (Adenosinemonophosphate) as a substitute for vernalization. We applied AMP in increasing concentrations from 1 to 675 ppm and found a linearly increasing growth-inhibition of the seedling, but no heading in any plants even with partial cold treatment. In the opinion of Tomita (1973) vernalization eliminates certain endosperm-specific protein fractions (via "vernalase", a hypothetical enzyme). In the winter wheat endosperm its effect can be simulated by trypsin treatment and demonstrated by electrophoresis. However, repeating Tomita's experiments, we were unable to demonstrate the presence of a proteinaeous vernalization inhibiting factor in the endosperm. Reciprocal transplantations between the endosperms and germs (embryos) of winter and spring wheats also resulted in exclusively vegetative plants in the spring wheat endosperm-winter wheat embryo combination (Barabas-Sagi, 1974). The primary effect of the endosperm could be excluded in this way directly, as well.

Cereal Research Institute, Szeged.

THE NUMBER OF WINTER WHEAT GENERATIONS IN THE FIELD (I); IN GLASS-HOUSE (II); AND UNDER CONDITIONED CIRCUMSTANCES IN EMBRYOCULTURE (III)

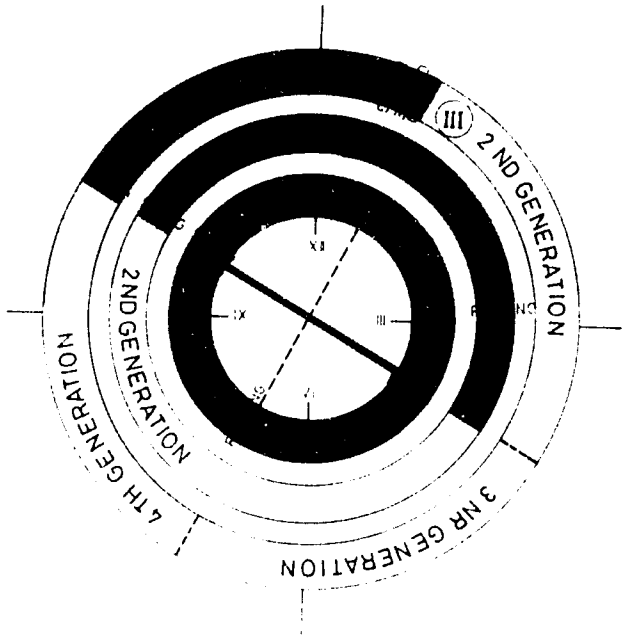

Figure 1

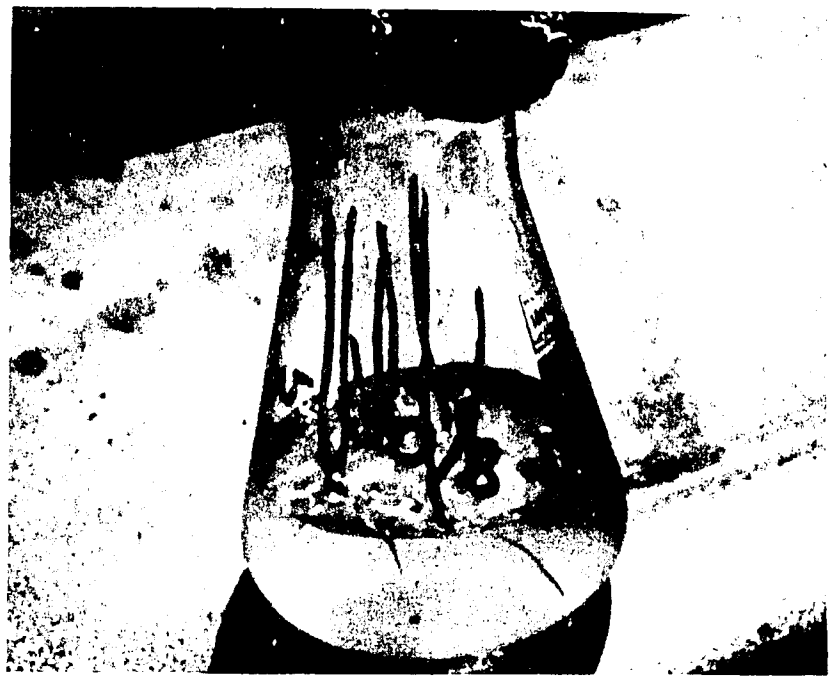

Figure 2

The latter experiment confirms Sereiskii's and Sluckaja's (1934) results from the thirties: the germ plays the main role in vernalization and not the endosperm. We repeated Tomita's experiments with several winter wheat varieties without success (Barabas-Sagi, 1974).

Glouschenko et al., (1973) tested the effect of 20 different compounds for partial substitution in the vernalization of wheat. We retested a few of the most effective ones, but the results were not very satisfying in this case, either (Barabas, 1978).

The effectiveness of the cytokinins was demonstrated in the replacement of natural cold vernalization carried out by Reda and Fatma in 1976. Several authors have already applied it to various plants for this purpose with success. For example, Michniewicz and Kamienska (1964) reported its flower initiation effect in unchilled chicory.

The effect of kinetin was studied in eight experiments in 0, 5, 20, 100 and 200 ppm concentrations. A temperature of 2°C in six steps (20, 25, 30, 35, 40, 45) was applied to vernalize "Sava" winter wheat seedlings. Those plants which headed on the 77th day from the beginning of the experiment were appropriately vernalized (Barabas-Csepely, 1978). A cold treatment of over 40 days already resulted in over-vernalization. A cold treatment of under 40 days alone was not enough. But a 30-day cold treatment (Fig. 3.), together with only 5 ppm kinetin was sufficient. With 20 to 100 ppm

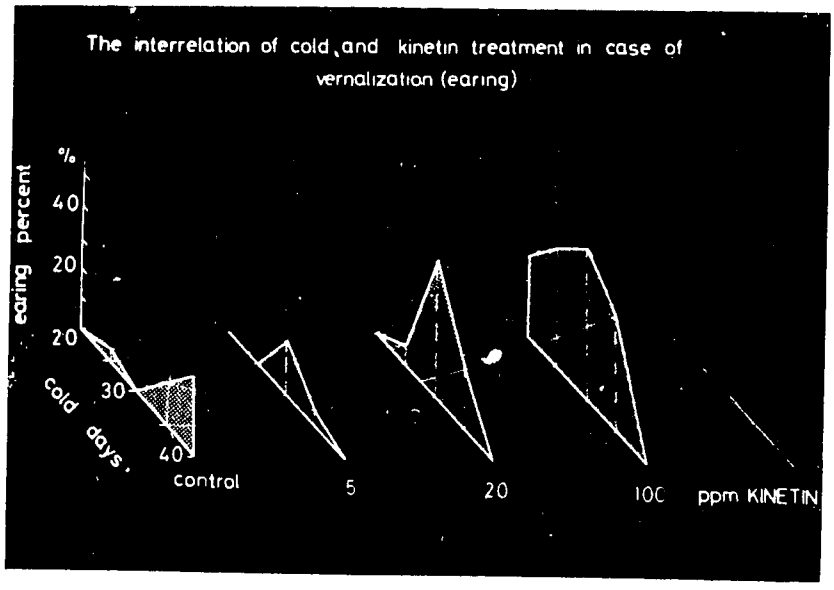

Figure 3

kinetin twice as many plants headed relative to the control; 100 ppm kinetin plus 20 days cold treatment was as effective as a 40-day cold treatment without kinetin (50% less cold treatment). We could not demonstrate the effect of 200 ppm kinetin, because this dose was toxic.

It seems that 5-100 ppm kinetin does not simply stimulate the vernalization process, but partially replaces the function of the cold as well. When the seedlings receive enough cold, kinetin does not further accelerate heading, but rather inhibits it. This last slide demonstrates the fact that the optimal 40 days of cold plus any dose of kinetin leads to practically total inhibition of heading.

The chemo-vernalization effects of some other cytokinins were also tested in similar ways. Though kinetin proved the best, benzimidazol and 6-benzyladenine were also effective in shortening the vernalization time of winter wheat. It is possible that the cytokinins operate as general process stimulators, but do not influence any specific step in the metabolism.

Summing up: a heading percentage comparable to that of the 40-day vernalization period without kinetin can be obtained in 20 days with 100 ppm kinetin. Consequently, this method can reduce the vernalization time by half and thereby accelerate winter wheat generations. The effect of cytokinins on vernalization is useful in the practice of plant research work.

References

Abramova, A. V. & O. I. Gurinovich. 1972. Post-harvest ripening of spring wheat seeds as affected by the anatomy and biochemistry of pericarp and seed testa. Sel'skohozyaistvennaya Biologiya 7:3:449-451. Ru, 8 ref. Sel'skohozyaistvennyi Institut, Leningrad, USSR.

Barabas, Z. 1978. Acceleration of winter wheat generations by reduced vernalization. In: 6th Internat. Cereal and Bread Congress, Winnipeg, Manitoba, Canada, pp: 6.

Barabas, Z., and I. T. Csepely. 1978. Shortening vernalization of winter wheat with kinetin. EUPHYTICA 27:831-835.

Barabas, Z., and F. Sagi. 1974. Is chemical vernalization possible in winter wheat? Cereal Res. Comm. 2:65-76.

Bruinsma, J. and S. S. Patil. 1963. The effect of 3-indolacetic acid, gibberellic acid and vitamin E on flower initiation in undervernalized Petkus winter rye. Naturwiss. 50:505.

Devay, J. 1967. The effect of various antimetabolites in the course of vernalization. Acta Agron. Acad. Sci. Hung. 16:251-252.

Dietrich, K. 1924. Uber die Kultur von Embryonen ausserhalb des Samens. Flora 117:379-417.

El-Antably, M. M. Hamed. 1976. Endogenous hormone levels in vernalized roots and shoots of wheat seedlings. Biochem. Physiol. Pflanz. 170:59-66.

Glouschenko, I. E. et al., 1973. Effects of different chemicals for the vernalization rate of wheat (Russian). Doklady VASHNIL 8:2-4.

Hanisova et al. 1975. Treatment to shorten the development period of celery (Apium graveolens, L.). J. Hortic. Sci. 50:97-104.

Hess, D. 1979. Novenyelettan. Az anyagcsere es fejlodes molekularis es biokemiai-fiziologiai alapjai. Natura. 1979.

Ishikawa, K. et al. 1975. Effect of nucleic acid antimetabolites on the vernalization of winter wheat. Plant Cell. Physiol. 16: 5:292-293.

James, N. I. and S. Lund. 1960. Meristem development of winter barley as affected by vernalization of potassium gibberellate. Agron. J. 52:508-510.

Lang, A. 1956. Induction of flower formation in biennal Hyosciamus by treatment with gibberellin. Die Naturwissenschaften. 43:284-285.

Michniewicz, J. and A. Kamienska. 1964. Flower formation induced by kinetin and vitamin E treatment in cold-requiring plant (Cichorium intybus L.) grown under noninductive conditions. Naturwiss. 51:295-296.

Nutman, P. S. 1941. Studies in vernalization of cereals. VII. A study of the conditions of formation and the subsequent growth of dwarf embryos of rye. Ann. Botany (London S. n.s.): 353-374.

Pauli, A. K. et al. 1962. Flowering response in winter wheat as influenced by temperature, light and gibberellic acid. Crop Sci. 2:271-274.

Rapoport, L. and J. Bonner. 1960. Interaction of gibberellin, vernalization, photoperiod and temperature in the flowering endive. Plant Physiol. 35:98-102.

Reda, Fatma. 1976. Endogenous cytokinins in vernalized winter wheat grains. Planta. 130:265-268.

Sarkar, S. 1958. Versuche zur Physiologie der Vernalisation. Biol. Zbl. 77:1-49.

Sereiskii, A. and M. Sluckaja. 1934. On the nature of vernalization. (Russian) Bot. Zurn. SSSR. 19:311-320.

Teich, A. H. 1980. Germinating immature winter wheat seed. Cereal Res. Comm. 8:3 (in press).

Tomita, T. 1963. Studies on vernalization and flowering substances. II. Vernalization like phenomens in winter wheat and radish treated with flower-promoting substances. Tohoku J. Agric. Res. 14:13-24.

Tomita, T. 1964. Studies on vernalization and flowering substances. IV. Bioassay on flowering activities of natural and chemical substances by the injection into the empty endospermic space of young winter wheat seedlings. Tohoku J. Agric. Res. 15:1-11.

Tomita, T. 1968. Flowering activities of natural and chemical substances injected into the cavity of empty endospermic space of young winter wheat seedlings. In: Wightam, F. and G. Setterfield (Ed.). Biochemistry and Physiology of Plant Growth Substances. Ottawa p. 1399-1413.

Tomita, T. 1973. Crop diagnostic study and its application. Vernalization in winter wheat caused by protease. Bull. Nat. Inst. Agric. Sci., Japan, Ser. A No. 20:1-16.

Tomita, T. 1977. Enzymatic conception on vernalization in winter wheat. In: Kundrev, T. et al. (Ed.) Symp. on Plant Growth Regulators. Sofia. 1975. p. 63-70.

SPECULATIONS ABOUT SELECTION, WINTER HARDINESS AND NON-GENETIC DNA

D. G. Kenefick and C. L. Lay
United States

Abstract

Records show that plants which evolve at northern latitudes generally have larger nuclei than plants from southern regions. Diploid DNA content is highest for winter rye, followed by winter wheat, barley and oats, the order of intrinsic hardiness for these species. Changes in DNA content are attributed to variation in repetitive DNA and it has been proposed that large amounts have a functional benefit for plants grown in the diverse climate of temperate regions. Speculations are presented in this paper which extend these observations to an analysis of hardy and less-hardy cultivar traits. It is proposed that certain aspects of winter hardiness may not be explained by Mendelian genetics.

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Considerable variation in freeze survival potential exists in winter cereal germplasm. Discreet selection of genetic combinations offers the most immediate opportunity for further improvement in freeze resistance of cereals. A multiplicity of physical and chemical factors have been attributed to the survival of plants in a freezing environment. Yet, the kind of physiological information currently available has not complimented the selection approaches used and precludes the identification of heritable traits. Lacking these genotypes it has been difficult to rank the importance of physiological factors attributed to survival in a freezing environment.

Persistent efforts to improve hardiness by selection has also resulted in the emergence of undesirable traits in the hardiest cultivars. Typically, these cultivars have lower vegetative vigor, lower grain yield potential, and delayed heading dates when compared to less-hardy cultivars. It is not known if these traits are genetically linked to hardiness of if they reflect some advantage in survival. It is conceivable that prolonging growth initiation beyond danger of impending frost in the spring provides such an advantage. Delay of regrowth and reduction of metabolically directed cell hydration could presumedly be an asset for maintaining a low thermal deathpoint of tissue (15). However, any delayed growth response is also viewed as an impairment to grain yield (18). Therefore, genetic identification of traits contributing to hardiness and an elimination of those which reduce the agronomic desirability of hardy phenotypes could provide a better understanding of freeze resistance in plants, as well as improved cereal crop productivity.

Department of Plant Science, South Dakota State University, Brookings

Winter cereals offer a unique biological system for investigating gene regulation. The fact that these plants require low temperature in vernalization, which results in reproductive differentiation, strongly suggests an influence of temperature on DNA structure and ultimately genetic expression. It is our opinion that some aspects of cold acclimation, winter hardiness and growth response may be influenced by direct temperature effects on nuclear configuration. The extent to which the physical properties of the nucleus are affected by temperature in the evolution and selection of winter cereals has not been adequately investigated. The purpose of this report is to briefly review some of these possibilities and to suggest that some of the genetic and physiological complications associated with winter hardiness may escape conventional genetic analysis.

Temperatures in the range of 50 to 80 C are used to study *in vitro* melting characteristics of DNA (16). Segments of DNA containing guanosine (G) and cytosine (C) melt at higher temperature because of three hydrogen bonds between these bases. DNA strands rich in adenosine (A) and thymine (T) melt at lower temperatures since only two hydrogen bonds bind these bases. Transcription requires an unfolded DNA structure (19). Since lowering of temperature shortens hydrogen bonding distance, it is possible that temperature near freezing could affect decoding the genetic message. Nagl (17) showed condensation of polytene chromosomes in *Phaseolus* at temperatures of 12/8 C (day/night) when compared to 27/22 C or above, a result expected due to reduction of hydrogen bonding distance at low temperature. He concluded there are temperature dependent functional structures in polytene chromosomes.

The duration of the cell cycle in *T. aestivum* is inversely related to temperature. Meiosis was estimated to last 43, 24 and 18 hours, at 15, 20 and 25 C, respectively (2). Both embryo-sac mother cells (EMC) and pollen mother cells (PMC) of Chinese Spring underwent meiosis synchronously with about a 24-hour duration (3). However, growing plants under stress conditions at low temperature and short days induced pronounced asynchrony between meiosis in PMC and EMC within florets resulting in precocious female meiosis. Restoration of synchrony between male and female meiocyte development failed to occur 10 days after returning plants to normal conditions. Thus, evidence is available showing temperature effects on functions closely associated with nuclear expression.

The cline for winter rye production in the United States is at the most northerly latitude for cereals, followed by winter wheat, barley and oats at successively southerly latitudes. According to Klages (13), the distribution of winter cereals reflects their relative ability to withstand low freezing temperatures during the winter. Bennett (5) has shown that the amount of DNA per diploid genome is highest for rye (16.6 picograms) with decreasing amounts for wheat (11.5 pg), barley (10.9 pg) and oats (9.1 pg).

In higher plants the amount of DNA in the nucleus is strongly correlated with cell cycle length and minimum generation time (1, 4, 7). An analysis of DNA amounts in over 750 angiosperms (4) shows a trend of increased DNA with greater distance from the equator. Levin and Funderburg (14) suggest that the adaptive significance of genome size differences may reside in a biophysical parameter whose expression is a function of non-genetic DNA content rather than in the informational (inherited) content of the DNA. They perceive that plants which contain large amounts of "excess" DNA have a more complex regulatory ability and greater tolerance limits. Bennett (1) coined the term nucleotype to describe a course-control role for non-gentic DNA in phenotype expression with fine fidelity expressed at the gene levels.

Biologists have long been aware of "excess" DNA in eukaryotes (1). Estimates indicate as little at 5 to 10% of the total DNA express inherited traits in higher plants. The amount of single-copy DNA, that portion responsible for structural genes, has no apparent relation to genetic sophistication, whereas repetitive DNA accounts for a sevenfold difference among diploid species of Vicia (2). This information has important ramifications to our understanding of plant development, selection and evolution.

It is possible that selection for hardy phenotypes in a population may result because individuals with high G•C, in either single copy or repetitive DNA, are more responsive to adverse temperate. The selective advantage of a hardy individual may be the result of a greater tendency for DNA condensation at low temperature, thus restricting chromatin activity and lowering rates of RNA and protein synthesis as cell conservation measures. Conversely, it is proposed that less-hardy phenotypes are less affected by low temperature and would likely resume growth sooner, due to more "active" DNA sites made avaiable by an earlier "melt" of DNA strands with the progression of warmer temperatures. One consequence of the proposed feature for hardy nucleotypes is greater ability to divert cellular activities away from growth reactions which are viewed as detrimental, when temperature oscillates into the freezing range.

The foregoing discussion has attempted to provide some alternative explanations as to why the hardiest phenotypes generally have a slower growth response compared to less-hardy phenotypes. The speculation is that low temperature affects the nucleus and limits transcription. Freeze selection may favor nucleotypes having a high proportion of non-genetic DNA, they may have nuclear DNA with high G•C content in critical regions of the strand or a combination of these features. Obviously, comparative information on cell cycle time, nuclear volume and base composition of DNA between hardy and less-hardy cultivars is needed to evaluate this proposal. Factors other than those cited could influence transcription. Temperature has similar affects on nuclear protein-DNA associations. Both histone and non-histone proteins are known to selectively control genome expression (20). Freeze selection may differentially influence protein composition of the nucleus.

Temperature near freezing slows most biological processes and this fact can obscure the possibility of observing more subtle effects on transcription resulting from condensation of DNA. Research results from this laboratory provide supporting evidence for the idea that selection for hardiness has residual affects as observed for growth response, RNA and protein synthesis in winter barley seedling tissue immediately after cold acclimation. Additionally, freeze selection alters the activity of ribonuclease (RNase) and the electrophoretic form of RNase present in hardy and less-hardy cultivars, a distinction which exists without cold acclimation of tissue.

Dry weight increase of barley shoots was significantly reduced in the case of a hardy cultivar compared to a less-hardy one, when grown at 25 C after cold acclimation (10). In vitro RNA synthesis was curtailed at least 36 hours after cold treatment in the hardy cultivar, whereas rapid ^{32}P incorporation was observed within 10 hours after the change to 25 C for the less-hardy cultivar. Protein synthesis increased 3-fold above control values for a less-hardy cultivar in a 3-hour period at 25 C after cold acclimation, but no change was observed during the period for a hardy cultivar (11). Addition of IAA during isotope treatment of shoot tissue doubled incorporation of label in protein in cold acclimated less-hardy samples, but no change was observed in hardy shoots.

A consistently low level of RNase activity has been observed in shoot tissue of the 12 hardiest winter barley phenotypes examined in a group of 90 tested (9, 12). A correlation of this RNase expression with hardiness level occurs only after freeze selection (11). Quantitation of RNase by rocket immunoelectrophoresis has shown equal amounts of enzyme in both cultivars, therefore specific activity is lower in the hardy type (8).

More recently it has been demonstrated that hardy phenotypes have single electrophoretic form of RNase in expanding green-leaf tissue compared to four activity bands in acrylamide gels containing soluble tissue extracts from a less-hardy cultivar (6). The distinction in RNase activity between hardy and less-hardy phenotypes can be made on individual plants and does not require tissue acclimation. However, we have demonstrated that this multiple banding pattern of RNase in the less-hardy cultivar is altered by cold acclimation of tissue (6). It may be that DNA template activity for RNase is altered by low temperature.

It is our opinion that RNase will be useful as a biochemical probe in research on hardiness inheritance. The intensity of selection for freeze resistance in winter barley determines the kind of RNase expression. RNase inheritance studies are now underway as a means to more closely examine the association. A determination of the number of loci involved in RNase expression will be useful in identification of the chromosome(s) containing genes for hardiness.

Should we find that the enzyme does not exhibit Mendelian ratios, a reason will exist to further suspect regulation is in-

fluenced by the portion of DNA flanking the enzyme codon. Currently, we are considering this possibility on the basis of a single RNase activity band in the hardy phenotype and also because changes in RNase forms occur in the less-hardy cultivar after low temperature treatment of the tissue, both of which can be explained by restricted DNA template activity. Also, the results reported on differentials in growth rate and in RNA and protein synthesis between cultivars can be interpreted in this manner.

Nuclear DNA content generally is shown to be larger in plants which have evolved in northern compared to southern latitudes. This same DNA relationship exists between winter cereals when evaluated against their geopgraphic distribution. The common evolutionary explanation provided for these results is the need for a more complex phenological regulation of plants when grown under climatic diversity. Presumedly such differences in nuclear size reside in the non-genetic portion of DNA. If DNA amount is not vastly different between hardy and less-hardy cultivars within a species, then DNA base composition and/or nuclear protein may be influenced by selection for the hardiest phenotypes, which could account for slow growth responses and reduced RNA and protein synthesis after cold acclimation. Such possibilities could provide an additional reason for complex genetic traits observed in hardiness that may not be detected by Mendelian analysis.

Literature Cited

1. Bennett, M. D. 1972. Nuclear DNA content and minimum generation time in herbaceous plants. Proc. R. Soc. London B 181:109-135.
2. Bennett, M. D. and J. B. Smith. 1972. The effects of polyploidy on meiotic duration and pollen development in cereal anthers. Proc. Roy. Soc. Lond. B 181:81-107.
3. Bennett, M. D. 1973. Nuclear characters in plants. In "Basic Mechanisms in Plant Morphogenesis". Brookhaven Symposium Biology 25.
4. Bennett, M. D. and J. B. Smith. 1976. Nuclear amounts in angiosperms. Phil. Trans. Roy. Soc. Lond. B 274:227-274.
5. Bennett, M. D. 1976. DNA amount, latitude, and crop plant distribution. Env. and Exp. Botany 16:93-108.
6. Blake, T. K. 1979. Determination of RNase phenotypes in winter barley populations. M.S. Thesis. South Dakota State University, Brookings.
7. Cavalier-Smith, T. 1978. Nuclear volume control by nucleoskeletal DNA, selection for cell volume and cell growth rate, and the solution of the DNA C-value paradox. J. Cell Sci. 34:247-278.
8. Hawthorne, S. B., R. P. Hillam and D. G. Kenefick. 1980. Serological characterization of a ribonuclease from Hordeum vulgare. Phytochemistry 19:1587-1591.
9. Johnson, C., R. Wong, and D. G. Kenefick. 1975. The relationship of RNase levels to winter hardiness in barley. Barley Genetics III. Garching, FRG. p 508-516.

10. Kenefick, D. G. and E. I. Whitehead. 1970. Growth and related nucleic acid changes in a hardy and nonhardy winter barley following cold acclimation. Barley Genetics II, Washington State University Press, Pullman, p. 378-387.
11. Kenefick, D. G., C. Johnson, and E. I. Whitehead. 1974. Characteristics of protein synthesis and RNase activity in Hordeum in relation to temperature adaptation. p. 505-511. In R. L. Bieleski, A. R. Ferguson and M. M. Cresswell (eds). Mechanisms of Regulation of Plant Growth. R. Soc. N. Z. Wellington, Bull 12.
12. Kenefick, D. G., B. J. Kolp and E. I. Whitehead. 1977. Relationship of ribonucleic acid degrading enzymes to survival levels of winter barley phenotypes. Crop Sci. 17:749-753.
13. Klages, K. H. W. 1942. Ecological Crop Geography. MacMillan, New York.
14. Levin, D. A. and S. W. Funderberg. 1979. Genome size in angiosperms: temporate versus tropical species. Am. Nat. 114:784-795.
15. Metcalf, E. L., C. E. Cress, C. R. Olien, and E. H. Everson. 1970. Relationship between crown moisture content and killing temperature and three wheat and three barley cultivars. Crop Sci. 10:362-365.
16. Metzler, D. E. 1977. The chemical reactions for living cells. Chapter 2. Biochemistry. Academic Press, New York.
17. Nagl, W. 1970. Temperature-dependent functional structures in the polytene chromosomes of Phaseolus, with special reference to the nucleolus organizers. J. Cell Sci. 6:87-107.
18. Reitz, L. P. 1974. Breeding for more efficient water use -- is it real or a mirage? Agri. Met. 14:3-11.
19. Weintraub, H. and M. Groudine. 1976. Chromosomal subunits in active genes have an altered conformation. Science 193:848-856.
20. Weisbrod, S. and H. Weintraub. 1979. Isolation of a subclass of nuclear proteins responsible for conferring a DNase I-Sensitive structure globin chromatin. Proc. Natl. Acad. Sci. USA, 76:630-634.

VARIATION IN EAR DEVELOPMENT IN SOME WINTER WHEAT CULTIVARS

L. A. Hunt
Canada

Abstract

Seventeen winter wheat cultivars were used in a field study of the durations of the growth phases from double ridges to stamen initiation (spikelet initiation), from stamen initiation to anthesis (ear growth), and from anthesis to maturity (grain filling). The work was undertaken as the first step in a program to define the extent of variation between genotypes in the relative durations of the various phases of the life cycle, and to determine whether the distribution of time among the various phases is optimum for yield in cultivars currently used in Ontario.

Variation in the duration of all growth phases was identified, with spikelet initiation lasting from 18 days for Peking-10 to 28 days for Hyslop and Sv. Solid, ear growth from 21 days for Aurora to 27 days for Karat, and grain filling from 35 for the late maturing Sv. Solid to 42 days for the earliest cultivar, Peking-10. Further work will be necessary to determine if the variation is maintained in different environments, and to define the optimum distribution of time between the various phases.

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Introduction

Much research has been concentrated on describing the process of ear development (Bonnett, 1936, 1966; Sharman, 1947), and on recognizing events that could form the basis of numerical scales of development (Andersen, 1954; Banerjee and Wienhues, 1965). Other research has used just a few of the identifiable events to divide the life cycle into phases - e.g. the vegetative phase, the reproductive phase, and grain filling - and has concentrated on exploring the effects on yield and its components of variation in the environment experienced during the various phases (e.g. Aitken, 1974; Allison and Daynard, 1976; Thorne, Ford and Watson, 1968). From some of this research it has been proposed that certain relative durations of the phases of the life cycle may lead to higher numbers of spikelets or higher yields than others (e.g. Rawson, 1970; Wall and Cartwright, 1974). Such a proposition is of significance in breeding, and research is necessary to define the extent of variation between genotypes in the relative duration of the various phases of the life cycle, and to determine whether the distribution of time among the various phases is optimum for yield in current cultivars. The work reported in the paper was undertaken as an initial step to provide information on the variation that may exist in the duration of various phases of ear development.

Department of Crop Science, University of Guelph
Guelph, Ontario

Phases of Development

A general scheme of ear development is presented in Fig. 1, which is based on a diagram presented by Gallagher (1979) and on work by Kirby (1974). In this diagram, primordia number has been plotted agaist time, although an accumulated temperature base may be better for certain field conditions where changes in temperatures from one part of the life cycle to another could cause compression or elongation of the different phases. Also, the spikelet and floret initation phases have been shown as distinctly separated whereas in reality floret initiation may commence before the terminal spikelet has been formed and the spikelet phase terminated. The diagram shows, however, that the spikelet initiation phase commences before the growing point assumes the form commonly described as "double ridges", in line with recent work which has shown that double ridges occur when a variable proportion of the spikelets have been initiated (Rawson, 1971; Kirby, 1974).

Determination of the end of the spikelet initiation phase can be made with relative ease by noting stamen initial or terminal spikelet formation. By contrast, pinpointing the end of the floret initiation phase is difficult because the glumes and lemmae cover the apical meristem of the spikelet, so that the number of florets can only be determined by a lengthy dissection. This is unfortunate since the period of a month or so preceding anthesis, presumbly during which much floret death is occuring, is of prime significance in determining yield (Fischer, 1975). However for the moment, the floret initiation and development phases will be considered together as that period from terminal spikelet formation to anthesis. Determining the end of the grain filling phase is also difficult, and can most accurately be achieved by following the pattern of dry matter accumulation in the ear. However, for much work dry weight determinations are too time consuming. An alternative is to use a dye such as eosin to determine the time at which translocation to the glumes ceases. This procedure was used to obtain some of the data reported here.

Plant material

The cultivars selected for study were drawn from a wide geographical range; many had been included in previous International Winter Wheat Performance Nurseries. All cultivars were grown at the Elora Research Station (43.7°N; 380 m elevation) in Ontario, Canada. The material had been planted on Sept. 8, 1977 at a seeding rate of 130 kg/ha, and had been fertilized with 90 kg/ha N on April 18, 1978. Samples of twenty of the largest tillers were harvested at random from each of four replicate plots for the determination of the double ridge and stamen initiation stages, and later for determination of physiological maturity. This latter stage was determined through a procedure which involved placing the lower end of the stems of twenty harvested culms into eosin solution, and noting whether the eosin dye was translocated to the glumes some 24 hours later.

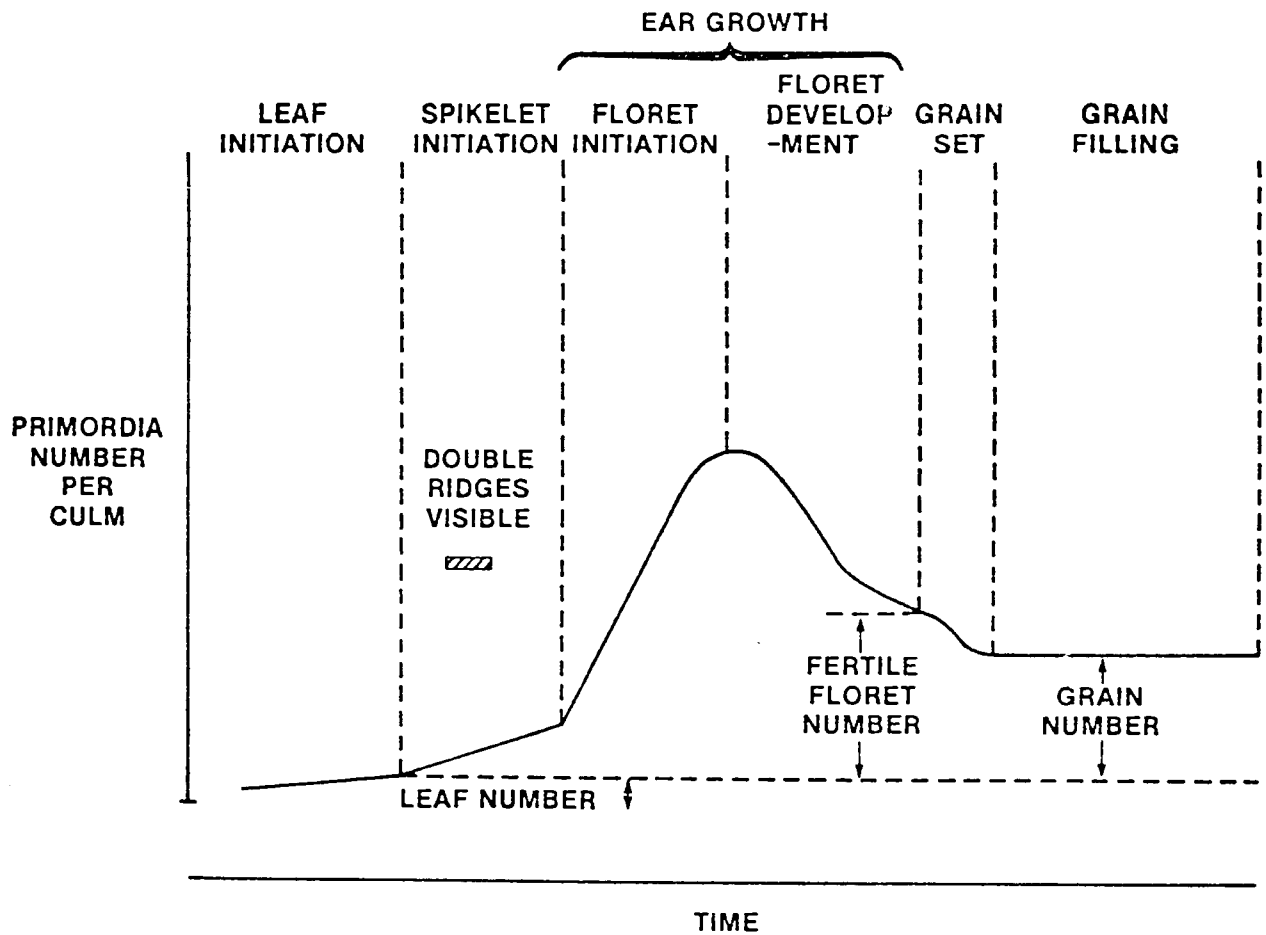

FIG. 1 GENERAL SCHEME FOR EAR DEVELOPMENT

Results and Discussion

The data of Table 1 show that there was considerable variation in the time at which a stamen initiation occurred - from 18 days after May 1 for Peking-10 to 27 days for the local cultivar Fredrick, and 36 for Sv. Solid. This period does not fully reflect the spikelet initiation phase because initiation with the later cultivars may have occurred after May 1. However, when double ridges is taken as an indicator of the start of spikelet initiation, the duration of the spikelet phase varied from 18 to 28 days. It thus seems clear that varieties such as Peking-10 and Jubileynaya-50 not only reached the stamen initiation stage earlier than many other cultivars, but also devoted less time to spikelet initiation. Such a reduction in the duration of the spikelet initiation phase may result in fewer spikelets per spike, although the effects of a shorter duration could possibly be offset by a faster rate of initiation. In this regard differences in the rate of initiation of spikelet primordia have been noted. For example, Allison and Daynard (1976) reported that Sonora-64 initiated spikelets at a faster rate than other cultivars in their studies.

The duration of the ear growth phase varied less than the spikelet phase, from 27 days for the Austrian cultivar Karat to 21 days for Aurora and 22 days for a number of cultivars including Jubileynaya-50, Fredrick and Sv. Solid (Table 1). The ear growth phase includes both floret initiation and floret develpment so that cultivars in which the phase is of long duration have a high potential either for the floret initiation or for good floret development, or a combination of the two. Because the number of florets initiated is usually greatly in excess of the number that complete their development and are fertile at anthesis (see Gallagher, 1979), a reduction in the duration of the ear growth phase could result in a decrease in the number of florets initiated, but no decrease in the number of florets that complete development to anthesis. More detailed analysis in which floret initiation is separated from development in a range of genotypes is necessary to provide information on this aspect.

The period from anthesis to physiological maturity varied from 42 days for Peking-10 to 35 days for Sv. Solid (Table 1). There was a marked tendency for the later maturing cultivars to have the shorter filling period, presumably because of higher temperature later in the season. However, differences in the duration of the filling period were still apparent when cultivars were ranked according to maturity groups (Table 2). For those cultivars which matured in 87 days, Aurora had a 40 day filling period while Hyslop took only 37 days; for the 91-93 day cultivars, Karat filled in 41 days as contrasted to 35 days for Sv. Solid. The filling period duration, as measured in this work, does not correspond closely to the effective grain filling period as defined by Daynard et al. (1971) and used in work with corn in which grain yield has been associated with filling period duration (e.g. Daynard and Kannenberg, 1976). Therefore, further work will be necessary to determine whether the differences as measured here are apparent when a dry weight accumulation move is used to characterize the filling period.

Table 1. Development of winter wheats at Elora, Ontario in 1978.

Cultivar	Origin	Duration of various phases of development (days)				
		Spikelet initiation[1]		Ear growth[2]	Filling[3]	Total[4]
Peking-10	China	18	(18)	25	42	85
Blueboy	U.S.A.	22	(24)	23	41	86
Bezostaya-1	USSR	22	(22)	24	40	86
Jubileynaya-50	USSR	23	(21)	22	41	86
Beau	U.S.A.	23	(24)	22	40	85
Priboy	USSR	23	(25)	25	40	88
NS-984	Yugoslavia	24	(22)	24	40	88
Romanian	Romania	24	(22)	25	38	87
Karat	Austria	24	(22)	27	41	92
Aurora	USSR	26	(24)	21	40	87
Fredrick	Canada	27	(23)	22	38	87
Grana	Poland	27	(23)	24	39	90
Hyslop	U.S.A.	27	(28)	23	37	87
Maris Huntsman	U.K.	28	(23)	23	37	88
Svalof Hildur	Sweden	31	(23)	26	36	93
Benno	Germany	32	(20)	23	36	91
Svalof Solid	Sweden	36	(28)	22	35	93

1. May 1 to stamen initiation(double ridges to stamen initiation).
2. Stamen initiation to anthesis.
3. Anthesis to eosin ripeness.
4. May 1 to eosin ripeness.

Table 2. Filling period duration of winter wheats at Elora, Ontario in 1978.

Maturity group (days from May 1)	Cultivar/line	Duration of filling period (days)
87	Aurora	40
	Romanian	38
	Fredrick	38
	Hyslop	37
91-93	Darat	41
	Sv. Hildur	36
	Benno	36
	Sv. Solid	35

Distribution of the time taken from May 1 to maturity differed markedly between the various cultivars (Table 3). Spikelet initiation accounted for only 21% of the time with Peking-10, but for 39% with Sv. Solid. Ear growth duration varied less, from 29% of the total period for Peking-10, Romanian and Karat to 24% for Sv. Solid; while filling duration varied from 50% with Peking-10 to 37% with Sv. Solid. The 50% figure seems high, but is in line with work reported by Rasmusson et al., (1979) showing that three barley cultivars spent more than 50% of their growing period in grain filling in a growth chamber at 21C.

Table 3. Percentage of the time from May 1 to maturity in various phases of growth for winter wheat at Elora, Ontario in 1978.

Cultivar	Origin	Percentage distribution of growth stages.		
		Spikelet initiation[1]	Ear growth[2]	Filling[3]
Peking-10	China	21	29	50
Blueboy	U.S.A.	26	27	47
Bezostaya-1	USSR	26	28	46
Jubileynaya-50	USSR	27	26	47
Beau	U.S.A.	27	26	47
Priboy	USSR	26	28	46
NS-984	Yugoslavia	27	27	46
Romanian	Romania	28	29	43
Karat	Austria	26	29	45
Aurora	USSR	30	24	46
Fredrick	Canada	31	25	44
Grana	Poland	31	26	43
Hyslop	U.S.A.	31	26	43
Maris Huntsman	U.K.	32	26	42
Svalof Hildur	Sweden	33	28	39
Benno	Germany	35	25	40
Svalof Solid	Sweden	39	24	37

1. May 1 to stamen initiation.
2. Stamen initiation to anthesis.
3. Anthesis to eosin ripeness.

General Discussion

This work reports an initial attempt to identify and characterize variation that exists in winter wheat for the duration of three major growth phases - viz. spikelet initiation, ear growth, and grain filling. The data suggest that variation in the duration of all three phases is present, but further work will be necessary to determine whether the variation is maintained when the cultivars are grown in different environments, and when different techniques are used to characterize the phases.

Variation in the duration of the three phases has been reported in other work. With winter wheat, Gotoh (1978) presented data for field grown material which indicates that the spikelet phase (double ridges to terminal spikelet) varied from 8 days with Akasabishirazu-1 to 19 days for Kitakamikomugi, while the ear growth phase (initiation of floret primordium differentiation to heading) varied from 41 days with Akasabishirazu-1 to 31 days with Nanbukomugi. With spring barley, Rasmusson et al.,(1979) reported an extensive search for lines that differed in the number of days in the grain filling period, and identified cultivars that could be classed into three distinct types which spent 25, 33, or 39% of their growth cycle in grain filling when grown in field environments. It thus appears that variation is present, and that further attempts at identification and characterization would be warranted.

The attempts at identification and characterization of different phase lengths will achieve utility only when some of the identified material is used in breeding for optimum time allocation to the various growth phases. Such an optimum, which may be achieved when little time is wasted in establishing a potential for yield (e.g. floret number) that is far in access of what is present at maturity, will vary depending on environment and genetic background. The definition of such optima, however, is an urgent task of physiologists and breeders alike, and one which will require both breeding work to obtain different combinations of the various phase durations, and analytical work on the same genotypes when grown at many locations. More detailed examination of material in International Nurseries such as the IWWPN would help in this regard.

References

Aitken, Y. 1974. Flowering time, climate and genotype. Melbourne Univ. Press 193 pp.

Allison, J.C.S. and T.B. Daynard. 1976. Effect of photoperiod on development and number of spikelets of a temperate and some low latitute wheats. Ann. Appl. Biol. 83: 93-102.

Andersen, G. 1954. A method for determining stages of development in wheat.Physiol. Plant. 7: 513-516.

Banerjee, S. and F. Wienhues. 1965. Comparative studies on the development of the spike in wheat, barley and rye. Z. Pflanzenzuchtg. 54: 130-142.

Bonnett, O.T. 1936. The development of the wheat spike. J. Agric. Res. 53: 445-451.

_____.1966. Inflorescences of maize, wheat, rye, barley and oats: their initiation and development. Univ. Illinois Agr. Europ. Sta. Bull. 721.

Daynard, T.B., J.W. Tanner and W.G. Duncan. 1971. Duration of the grain filling period and its relation to grain yield in corn. Zea mays L. Crop Sci. 11: 45-48.

_____ and L.W. Kannenberg. 1976. Relationships between length of the actual and effective grain filling periods and the grain yield of corn. Can. J. Plant Sci. 56: 237-242.

Fischer, R.A. 1975. Yield potential in a dwarf spring wheat and the effect of shading. Crop Sci. 15: 607-613.

Friend, D.J.C., J.E. Fisher and V.A. Helson. 1963. The effect of light intensity and temperature of florel initiation and inflorescence development of Marquis wheat. Can J. Bot. 41, 1663-1674.

Gallagher, J.N. 1979. Ear development: processes and prospects. In "Crop physiology and cereal breeding" (J.H.J. Spretz and H. Kramer, eds) pp 3-9. Pudoc, Wageningen.

Gotoh, T. 1978. Improvement of wheat cultivars for winterhardiness and earliness. Misc. Pub. 1 Tohuku. Agr. Exp. Sta. 19-41.

Kirby, E.J.M. 1974. Ear development in spring wheat. J. Agric. Sci. 82: 437-447.

Rasmusson, D.C., I. McLean, and T.L. Tew. 1979. Vegetative and grain-filling periods of growth in barley. Crop Sci. 19:5-9.

Rawson, H.M. 1970. Spikelet number, its control and relation to yield per ear in wheat. Aust. J. Biol. Sci. 23: 1-15.

_____.1971. An upper limit for spikelet number per ear in wheat, as controlled by photoperiod. Aust. J. Agric. Res. 22:537-546.

Sharman, B.C. 1947. The biology and developmental morphology of the shoot apex in the gramineae. New Phytol. 46: 20-34.

Thorne, G.N., M.A. Ford, and D.J. Watson. 1968. Growth, development and yield of spring wheat in artificial climates. Ann. Bot. 32: 425-446.

Wall, P.C. and P.M. Cartwright. 1974. Effects of photoperiod, temperature and vernalization on the phenology and spikelet numbers in spring wheats. Ann. Appl. Biol. 76: 299-309.

DEPENDENCE OF THE INTERRELATIONSHIP BETWEEN YIELD, DAYS TO FLOWERING, DAYS TO RIPENING, THEIR DIFFERENCES AND PROPORTIONS, ON THE GEOGRAPHICAL LATITUDE, ESTIMATED WITHIN SITES OF IWWPN TRIALS.

H. Haensel, E. Geyer, and L. Seibert
Austria

Abstract

The influence of the number of days to flowering (prefloral period), days to ripening and days from flowering to ripening (postfloral period) on kernel yield within sites was investigated in IWWPN trials. The corresponding intervarietal regression coefficients were calculated for 8-9 selected European sites in five years and for all 30 sites of the northern hemisphere in one year (1971). It was found that b yield (y) on days to flowering (x_1) and on days to ripening (x_2) depended on the site latitude and changed from positive to negative values from north to south. The regression postfloral period (y) on prefloral period (x) was mostly negative and independent of site latitude. An 'Earliness-Index' (EI) = days to flowering divided by days to ripening (both from January 1) was used to measure the relative length of the prefloral period. EI site mean was independent of site latitude and site mean yield. However, within sites the intervarietal regression yield (y) on EI (x) changed from positive to negative values with decreasing latitude. In hot climates varieties with a lower EI, i.e., a relative shorter prefloral period, gave higher yields. Since the number of functional yield organs is partly determined by the duration of the prefloral period and the amount of assimilates transported and accumulated in these organs is partly determined by the length of the postfloral period, a certain balanced relationship of both periods within the possible total length of the vegetation period can be an important factor of yield formation, especially under more extreme climatic conditions.

Introduction

Breeders assume and have had the experience that earliness and lateness of varieties influence relative yields differently in different locations. There are many and various reasons why the date of flowering and/or ripening of a specific variety can be too late or too early to give high yields in a specific growing region. We shall consider only a few of them in the course of this discussion and we are aware that the duration of developmental periods is only one (complex) factor among others which control yield formation. Further we will not ask here, why varieties differ in dates of flowering and ripening at different latitudes,

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being aware that vernalization requirement, thermo-photoperiodic reaction and other lateness factors acting more or less independently may play a role (Martinic, 1975). We will consider here first of all the formal association of the results of physiological processes, as manifested in time of flowering and/or ripening on yield. Proceeding in this way, we do not believe that it is possible to solve breeding problems by simple regression equations. However, we are interested in this sort of information hoping that it may be of some use in breeding reflections.

We wanted to find out whether, and to what extent, the relative yield of a number of varieties depends on their relative ripening time and whether there is a systematic change of this dependence with site latitude. To answer these questions the IWWPNs offer a unique opportunity, as the same set of varieties with widely differing ripening times is grown at a number of sites with widely differing latitudes (Stroike et al., 1973, 1976, 1976a; Wilhelmi et al., 1977, 1978).

Method

The method used was: first to calculate intercultivar, i.e., within site correlations and regressions between yield and ripening periods and second, to plot the regression coefficients obtained at the different sites against the site latidude (Hansel, Schultes, Seibert, 1978).

The number of days to ripening can be divided into two periods: 1) the prefloral period, equal to the number of days to flowering; and 2) the postfloral period, equal to the number of days from flowering to ripening. By dividing the days to flowering by the days to ripening one obtains a measure of the relative length of the prefloral period which we call here 'Ripening-Index' (RI).

The terms 'prefloral' (= pre-flowering) and 'postfloral' (= post-flowering) periods are preferred to the often-used corresponding terms 'vegetative' and 'generative' periods because, from the standpoint of developmental physiology, the generative period begins with the 'double ridge' stage, and the dry matter production of the vegetative organs goes on after anthesis.

The number of days are recorded from January 1 at all sites. Because of the different sowing times and their influence on the duration, especially of the prefloral period and, most probably, differing methods used in determining the date of ripening, the between-site regressions are not given here. Within-site regressions should be least influenced by the differing methods.

Dependence of the within-site regression of yield on days to flowering and on days to ripening on site latitude.--In the 1971 IWWPN the regression of yield on days to flowering was calculated

Table 1. Intercultivar (within-site) correlations and regressions, IWWPN 1971, 30 cv. per site.

Site	Country	Site latitude degrees, dec.	Prefloral period = days to flowering Yield r	b	Days to ripening Yield r	b	Postfloral period Yield r	RI[1/] Yield r	Prefloral p. postfloral p. r
Svalof	S	55.6	.58**	1.24	.61***	1.92	-.30	.46**	-.77***
Wageningen	NL	51.5	.38*	1.54	.52**	.89	.07	.03	-.58***
Monsheim	D	49.6	.50**	.65	.41*	1.04	-.36*	.41*	-.86***
Weihenstephan	D	48.4	.47**	.79	.32	.55	-.22	.39*	-.36*
Wien	A	48.2	.23	.41	.14	.29	-.12	.17	-.60***
Martonvasar	H	47.4	.10	.12	.07	.10	-.10	.13	-.47**
Novi Sad	YU	45.1	-.38*	-.60	-.38*	-.55	-.11	-.17	.13
Rieti	I	42.4	-.78***	-1.18	-.64***	-1.66	.61***	-.70***	-.83***
El-Harrach	DZ	37.0	-.91***	-1.22	-.81***	-2.44	.87***	-.89***	-.95***

$$RI = \frac{\text{Days to flowering}}{\text{Days to ripening}}$$

within selected European sites plus one site in Algeria (Figure 1). The site latitude ranged from 37° to 55.6°. Significant positive, significant negative, and non-significant regression coefficients were found (Table 1).

When arranging the regression coefficients with decreasing site latitude, a trend reversion from positive values in the North to negative values in the South appears (Table 1). When plotting the regression coefficients against site latitude, a high correlation results. This holds true for the regression of yield on days to flowering (r = .92, b = .17) as well as for ripening (r = .98, b = .25) (Figure 2). Only at two sites near the 47th and the 48th degree northern latitude could no significant dependence of yield on days to flowering and days to ripening be found. However, this dependence increased steadily towards the northern and towards the southern sites. A similar close relationship (r = .90) was found between the site mean temperature and the corresponding b values.

For these European sites the latitude appears to characterize the combined effect of climatic factors (temperature, photoperiod, light intensity, precipitation) on yield as depending on ripening time to a high degree.

We assume that, when studying a larger number of varieties with a still wider range of ripening dates at each site, the dependence of yield on days to flowering and days to ripening would follow an optimum curve, since at each site (latitude) yield formation might become reduced and limited by too early and too late ripening. However, the range of days to flowering and ripening for optimal yields would be rather small in extreme northern and southern latitudes and wider in medium latitudes.

The same sort of investigation was made in 4 additional years for nearly the same European sites. Although the spectrum of varieties and the weather conditions changed during this period, the relaitonship between latitude and the yield-flowering and ripening regressions remained close and fairly constant (Table 2).

Table 2. Coefficients of correlation and regression for the dependence of the regression yield on days to flowering (b_{YF}) and yield on days to ripening (b_{YR}) on the geographical latitude at several sites in Europe in 5 years (30 cv. per site).

Year	Number of sites	Latitude-b_{YF} r	Latitude-b_{YF} b	Latitude-b_{YR} r	Latitude-b_{YR} b
1971	9	.93***	.15	.98***	.25
1973	8(7)	.92***	.20	.72*	.14
1974	8(7)	.88***	.32	.88***	.36
1975	8	.94***	.29	.90***	.29
1976	9	.70*	.30	.66*	.14

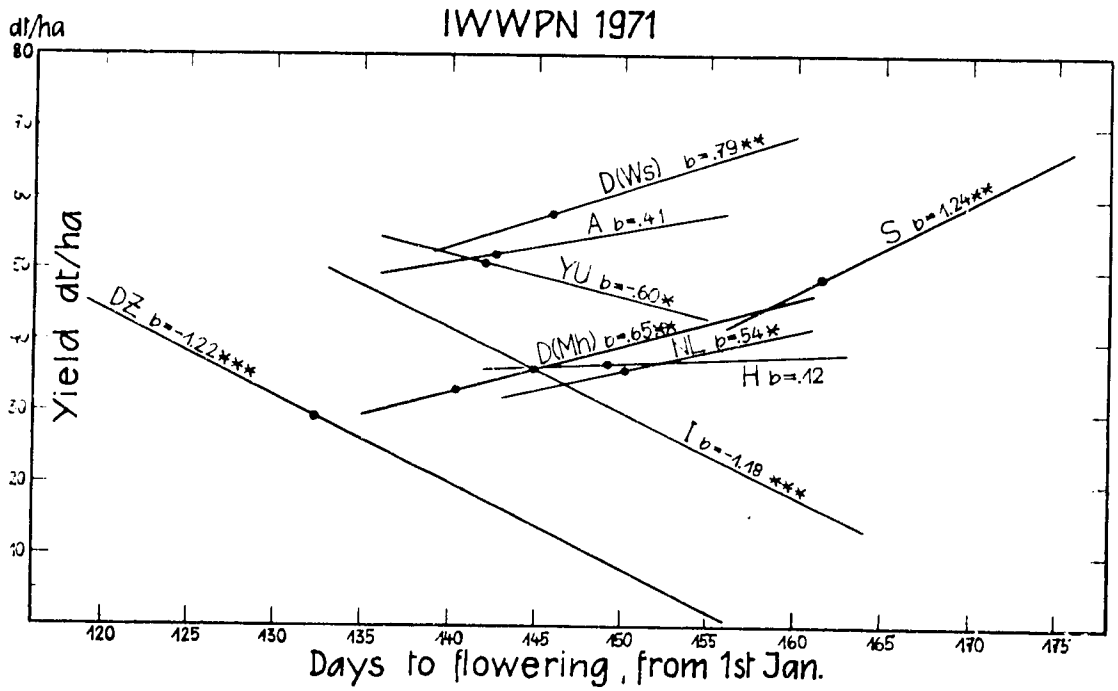

Figure 1. Within site (intercultivar) regressions for yield on days to flowering at 8 European sites and one site in Algeria (DZ) in the IWWPN 1971.

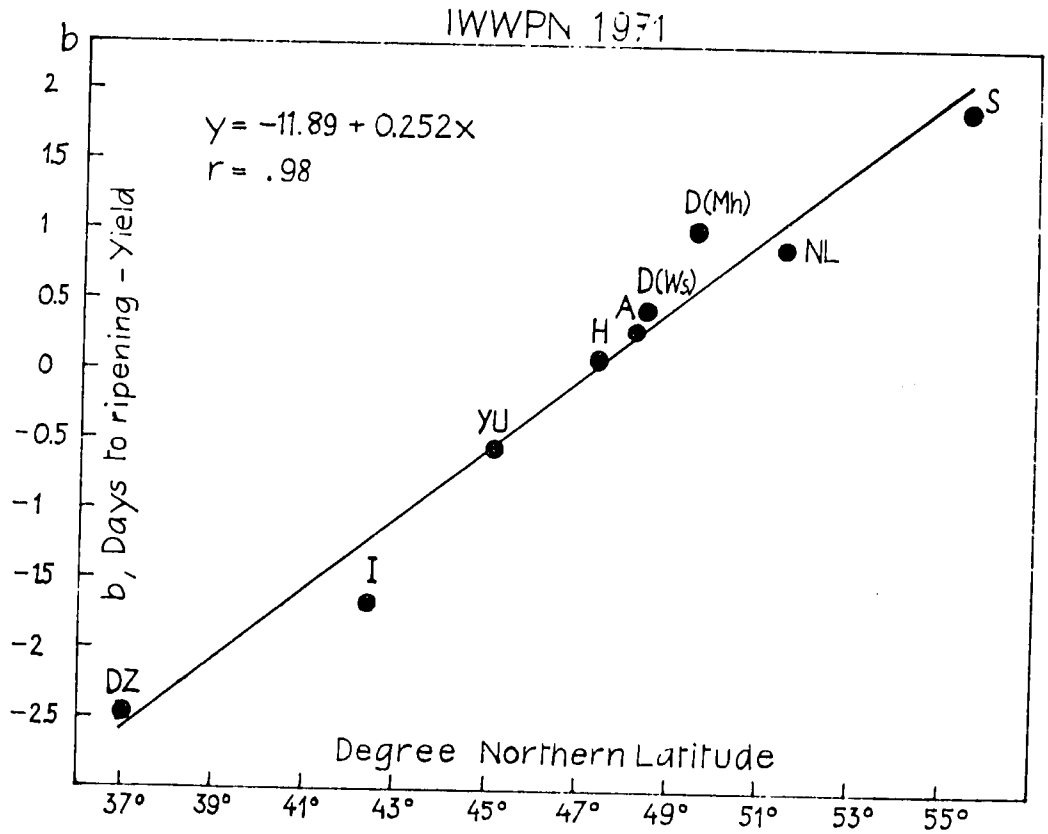

Figure 2. Dependence on the within site regression yield on day to ripening on the degree of northern latitude for 8 European sites and one site in Algeria (DZ) in the IWWPN 1971.

In Table 3 the number of positive, negative, and non-significant regression coefficients for yield on days to flowering and on days to ripening in these 5 years are given for each site. At the same site either significant positive and non-significant or significant negative and non-significant regressions occurred, except in a single case. (Monsheim: yield on days to flowering, 3 years +, 1 year n.s., and 1 year -)

The European breeder may deduce from these findings the following: 1) Only when breeding winter wheat for a restricted range of medium latitudes, one might select within a wider range of ripening classes without selecting against yield. 2) When in a specific growing area yield appears to be independent of ripening class in one or two years; in other years this might not be the case. When, e.g., earlier varieties tend to yield significantly better than later ripening types in two out of five years the breeder should prefer rather earlier ripening lines with the view of increasing average yield and yield stability.

In 1971, a similar study was made for all sites of the northern hemisphere (Figure 3). At sites between the 32nd and 46th degree all significant regressions for yield on days to flowering and on days to ripening were negative. But within this range of latitudes no dependence of these regressions on latitude was found. This reflects the widely differing climatic condition and stresses at sites of the same latitude, e.g., in the United States, in Korea, and in North Africa. On the other hand, the 12 European sites betweeen the 43rd and 56th degree n. latitude and situated within a comparatively small range of geographical longitude, showed a high, linear association (r = .93).

The prefloral and the postfloral period.--The total time to ripening of winter wheat is limited at each site by climatic factors, in the North by low temperatures in early spring and in the fall, and in the South mostly be high temperatures and drought in early summer or midsummer. The time left for growing and ripening has to be distributed between the prefloral and the post-floral periods. In the prefloral period the rate and duration of the initiation, formation and reduction of spikelets and flowers determines the number of flowers per m^2 which is at dispostion in the postfloral period (Hansel, 1955). In the postfloral period the rate and duration of grain filling decides lastly the yield per m^2. Therefore, and apart from the rate factor, the duration of each period per se and the proportion of both periods might influence yield formation depending on the climatic conditions of a location, e.g., a very high number of flowers developed in a relative long first period may be of little use when the following grain-filling period is too short a.s.o.

Within site regression of yield on postfloral period and its association with site latitudes.--This suggests the study of the influence of the postfloral period per se on yield and the relation between pre- and postfloral periods at different latitudes.

Table 3. Number of positive (+), negative (-), and not significant, P > 0.5 (ns) regression coefficients (b) within 8 sites of decreasing latitude, estimated for 5 years (1971, 1973, 1974, 1975, 1976).

Country	Site latitude degrees, dec.	b Days to flowering yield			b Days to ripening yield			b Postfloral period yield			b Prefloral period Postfloral period		
		+	ns	-	+	ns	-	+	ns	-	+	ns	-
S	55.6	5			4	1			3	2	1	1	3
NL	51.5	4	1		3	2			5			3	2
D	49.6	3	1	1	1	3			3	1			4
D	48.4	3	2		1	3			2	2			4
A	48.2		5			1	4		5			1	4
H	47.4		5			4	1		5				5
YU	45.1		2	3		3	2	1	4			2	3
I	42.4		1	3		1	3	2	2				4
(DZ)	37.0			2			1	1					1

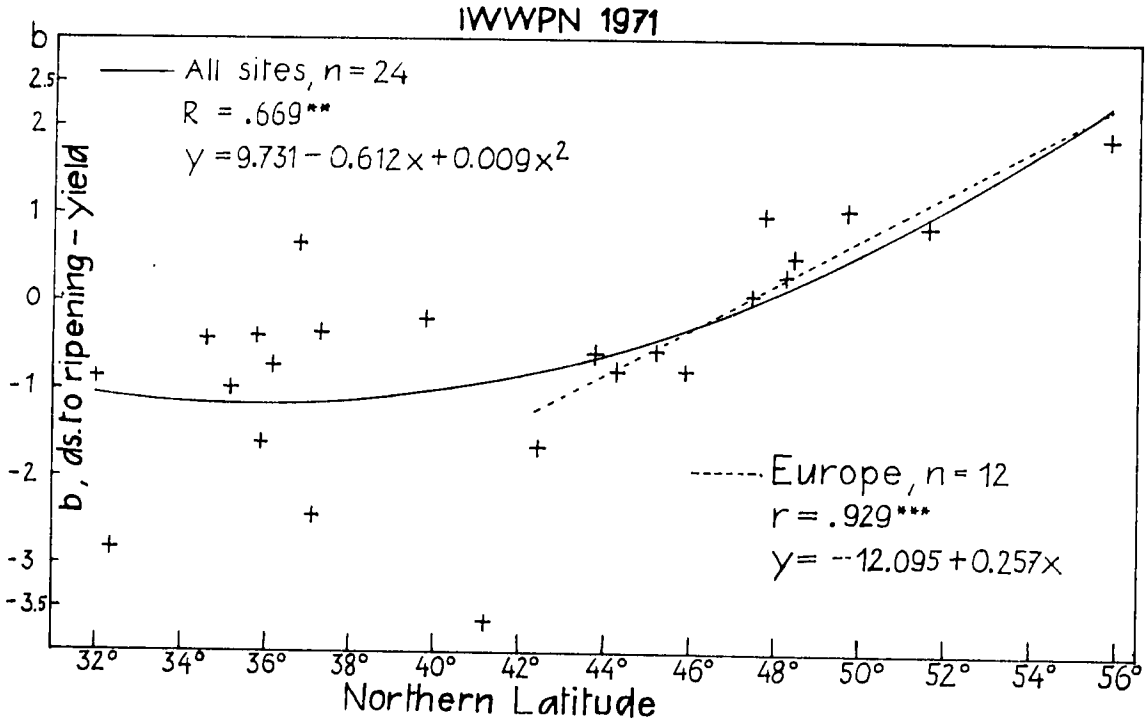

Figure 3. Dependence of the within site regression yield on days to ripening on the degree of northern latitude for 24 sites in the IWWPN 1971.

This was done in five years at the European sites (Tables 1 and 3). In all years postive, though not in every case significant positive within site regression coefficients for yield on length of postfloral period were found only at the most southern, dry sites. There, higher yielding varieties tended to have longer postfloral periods. At the northern sites this trend appeared to be reverted in some cases.

Within-site regression of postfloral period on prefloral period and its independence of site latitudes.--When the possible total length of the time to ripening is mostly determined by the climatic conditions of the site, then the average chance to build up a longer postfloral period will be greater for varieties with shorter prefloral periods, and this would occur more or less independent of the site latitude.

This was the case for the European sites as seen by the negative correlations between the length of the prefloral and the postfloral periods in 1971 and in other years (Tables 1 and 3).

A negative association of the length of these two periods is also seen at most of 24 sites in 1971 with latitudes ranging from 32° to 56° (Figure 4, Table 4). However, there remains a considerable amount of variance of the length of the grain filling period for varieties with the same date of flowering at each site. The regression of postfloral on prefloral period proved to be independent of site latitude ($r = .126$, $P > .5$). This and the possible importance of a specific physiological balance between both periods for optimal yield formation in a specific climate suggests seeing how far the proportion of both, as expressed by the Ripening-Index, determines the yield at different sites (Bingham, 1971).

Within-site correlation between yield and Ripening-Index and its association with site latitude.--The within-site correlation of yield on Ripening-Index showed the same trend as the correlation of yield on prefloral period, the single coefficients being rather low (Tables 1 and 4). This could be expected as a result of the mostly negative correlations between the length of the prefloral and the postfloral periods.

According to these results, in northern latitudes, late varieties with a longer prefloral and shorter postfloral period (= higher RI) than earlier varieties, give higher yields. In southern dry regions, earlier varieties with a shorter prefloral and longer postfloral period (= lower RI) than later varieties, yield better.

We suppose that the higher optimal RI in the North and the lower optimal RI in the South is the result of the longer respectively shorter possible growing period than an independent feature of adaptation.

Within this framework of interdependence finer differences in

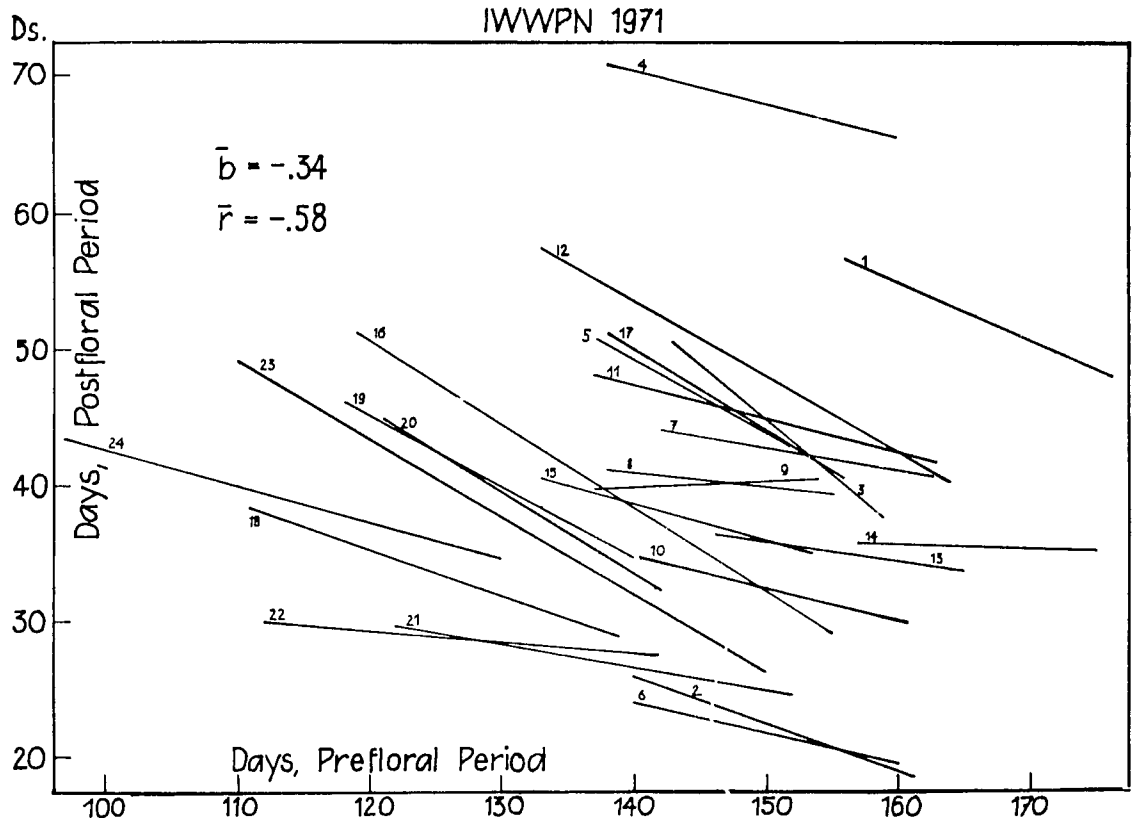

Figure 4. Dependence of the length of the postfloral period on the length of the prefloral period within 24 sites in IWWPN 1971. (Site numbers correspond to those given in Table 4).

Table 4. IWWPN 1971.

Site		Country	Northern latitude degrees, dec.	r Days to flowering yield	r RI 1/ yield	r Prefloral postfloral period
1	Svalof	S	55.58	.58	.46	-.77
2	Wageningen	NL	51.47	.38	ns	-.58
3	Monsheim	D	49.58	.50	.41	-.86
4	Weihenstephan	D	48.40	.47	.39	-.36
5	Wien	A	48.20	ns	ns	-.60
6	Zurich	CH	47.65	.50	.44	-.58
7	Martonvasar	H	47.35	ns	ns	-.47
8	Zagreb	YU	45.73	ns	ns	-.55
9	Novi Sad	YU	45.08	-.38	ns	ns
10	Fundulea	R	44.05	-.73	-.67	-.55
11	Tolbukhin	BG	43.67	-.45	-.38	-.56
12	Rieti	I	42.40	-.78	-.70	-.83
13	Nebraska	USA	41.17	-.75	-.37	-.41
14	Morioka	J	39.75	ns	ns	ns
15	Suwon	KO	37.27	ns	ns	ns
16	El-Harrach	DZ	37.05	-.91	-.89	-.95
17	Eskisehir	TR	36.75	ns	ns	-.87
18	Oklahoma	USA	36.10	-.43	ns	-.80
19	Karaj	IR	35.80	-.75	-.62	-.77
20	North Carolina	USA	35.70	ns	ns	-.90
21	Sulaimaniya	IRQ	35.08	-.80	-.72	-.66
22	Kabul	AFG	34.55	-.48	ns	ns
23	Shalimar	IND	32.25	-.83	-.78	-.94
24	Simla	IND	32.00	-.63	-.61	-.94

1/ $RI = \frac{\text{Days to flowering}}{\text{Days to ripening}}$

adaptation patterns may be accomplished by breeding. This concerns the total time to maturity as well as the proportion of the prefloral and postfloral periods, even within the same maturity class. The range of these factors allowing optimal yield formation depends largely on the latitude, the specific growing condition of a site, and their variance in different years. So the optimal Ripening-Index like the optimal length of the prefloral period will have a wider range in Mid-Europe than in Northern and Southern Europe and at most sites below the 44th degree northern latitude.

Literature Cited

Bingham, J. 1971. Physiological objectives in breeding for grain yield in wheat: The way ahead in plant breeding. Proc. 6th Congress of EUCARPIA, Cambridge. pp. 15-29.

Hansel, H. 1955. Entwicklungsrelationen verschiedener Organe von Weizen (Triticum aestivum L.). Z. f. Pflanzenzuchtung 35:117-136.

Hansel, H., V. Schultes, and L. Seibert. 1978. Intervarietale korrelationen zwischen kornertrag und reifezeitabschnitten, sowie zwischen 'praefloraler' und 'postfloraler' periode bei winterweizen, wintergerste und sommergerste. Ber. Arbeitstg. Arbeitsgemeinschaft d. Saatzuchtleiter, Gumpenstein. pp. 13-28.

Martinic, Z. 1975. Life cycle of common wheat varieties in natural environments as related to their response to shortened photoperiod. Z. f. Pflanzenzuchtung 75:237-251.

Stroike, J. E., V. A. Johnson, J. W. Schmidt, P. J. Mattern, and K. D. Wilhelmi. 1973, 1976 (April), 1976a (December). Results of the 3rd, 5th, and 6th International Winter Wheat Performance Nursery grown in 1971, 1973, and 1974. Bulls. 256, 276, and 279.

Wilhelmi, K. D., S. L. Kuhr, V. A. Johnson, P. J. Mattern, J. W. Schmidt. 1977, 1978. Results of the 7th and 8th International Winter Wheat Performance Nursery, grown in 1975 and 1976. Res. Bulls. 281 and 285.

DROUGHT AVOIDANCE IN WHEAT AND ITS RAPID ESTIMATION BY REMOTE INFRA-RED THERMAL LEAF CANOPY MEASUREMENTS

A. Blum
Israel

Abstract

Drought-avoidance is a drought resistance mechanism, manifested in avoidant genotypes by their relatively higher leaf water potentials under conditions of drought-stress. Leaf water-potential measurement by the common pressure-chamber technique is too slow to be used in routine screening work. Since water-stressed wheat was shown to have higher leaf temperatures, than non-stressed wheat, it was hypothesized that the rapid and remote measurement of canopy leaf temperatures with an infra-red thermometer could be developed into a screening technique for drought-avoidance in water-stressed breeding nurseries.

During two crop seasons, different wheat genotypes were grown and submitted to conditions of varying soil moisture stress. Wheat genotypes varied in their drought-avoidance as reflected by their non-time leaf water-potentials (measured with a pressure-chamber), ranging at peak stress from -19.3 to -32.6 bars.

At the same times that leaf water potentials were measured, leaf canopy temperatures were measured with a Barnes "Instatherm" infra-red thermometer. Ranking of wheat genotypes with respect to leaf temperature was quite consistent from day to day as water stress developed. At peak stress leaf temperature interval between extreme genotypes reached 6°C. Significant correlations were obtained between leaf temperatures and leaf-water-potentials over a range of wheat genotypes. Correlations became very significant as plant stress increased. The results indicate that in water-stressed breeding nurseries, drought-avoidant wheat genotypes can be revealed by infra-red thermal leaf canopy measurements. These measurements, together with other tests, allow to screen wheat germ plasm for drought resistance.

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NUMBER OF PRIMARY ROOTLETS IN WHEAT, A POTENTIALLY USEFUL TRAIT FOR BREEDING IMPROVEMENT

Slobodan Tomasovic
Yugoslavia

Abstract

A study was made of the number of primary rootlets of 40 genotypes of winter wheat Triticum aestivum spp. vulgare. Investigations were carried out under laboratory conditions, at room temperature and humidity, in 2 trials during two years (1973 and 1974). The data obtained were processed according to the block method of the analysis of variance. In addition to the common vulgare genotype, the analysis also included branched and four-rowed lines, as well as lines derived from the cross branched X vulgare. It was established that the branched gene complex caused the development of a larger number of primary rootlets than the common vulgare genotypes. A comparison was made of the studied genotypes and a large variation was recorded in the character "number of primary rootlets". The number of primary rootlets is an important quantitative character which can be used in breeding to discard superfluous genotypes. Thus, it speeds up the wheat breeding process.

Introduction

A study of root development at its initial stage is of great importance in the plant organism. At this development stage it is possible to get an insight into subsequent development of the plant. Thus, the development of primary rootlets of 14-day old plants allows conclusions relating to certain characters of the adult organism (Tavcar and Kendjelic, 1969). The number of rootlets is in positive correlation with the characters of adult plants influencing yielding capacity (grain yield, number of kernels/head, number of spikelets/head), and in negative correlations with lodging of plants (Kuburovic, 1971). Many investigators have established a direct connection between number of rootlets and yield (Kiricenko, 1969).

Primary rootlets originate from the embryo (germ). The number of primary rootlets is thus an indicator of embryo development (Saric, 1952). The same author studied also the effect of absolute seed weight on the number of primary rootlets in cereals. It was found that the number of primary rootlets depends on grain size. Larger seeds develop more primary rootlets than smaller seeds (Ravenska, 1965). Highly intensive genotypes have a larger number of primary rootlets than extensive genotypes (Manner, 1965).

Faculty of Agricultural Sciences, Institute for Breeding and Production of Field Crops, Marulicev trg 5/1, Zagreb

The subject of this paper is the study of the number of primary rootlets in winter wheat genotypes, both domestic and foreign strains. This character may be used as a parameter in breeding new genotypes with improved yielding capacity. It also speeds up the breeding process. In this way, already in early generations, superfluous genotypes can be discarded. Consequently, the number of primary rootlets is one of many useful traits that can contribute to the process of wheat breeding.

Materials and Methods

The number of primary rootlets was studied in two laboratory trials carried out in the course of two years. One of the trials (laboratory trial I) involved 25 genotypes: U1, Vigorka, Zekar, Mura, Zlatna Dolina, Sanja, Mirna, Sava, 715/70, Bankuti 1201, Fertodi 293, Erla Kolben, Gudin, Etoile de Choisy, Capelle Desprez, Helenka, Starke II, Maris Huntsman, Gaines, Centurk, Bezostaja 1, Kavkaz, S. Pastore, Libellula and Abbondanza. The choice of genotypes was guided by the genetic variability of trial material.

Trial I was set up under laboratory conditions, at room temperature and humidity, in 5 replications during 2 years (1973 and 1974). Seed germination was studied in plastic pots filled with sterilized quartz sand of 1 mm granulation. Of each genotype 250 plants were analyzed. Seed fractions larger than 2.8 mm were used. The number of primary rootlets was determined when the plants were 14 days old. The trial was processed according to the block method of the analysis of variance.

The other trial (laboratory trial II) included 15 genotypes of domestic and foreign strains. They comprised branched and one four-rowed line, and also lines derived from the cross Branched X vulgare.

The following common vulgare wheat genotypes were investigated: H303/1, Ranka, Ranaja, Fiorello, and Acciaio. The lines derived from crossing Branched X vulgare included: (Branched X H303/1) X Branched, Branched X Ranka, Branched X Ranaja, Branched X Fiorello, and Branched X Acciaio. The following branched lines were used: 199 a/72--very low, very branched red bearded, 2621/71--branched red bearded of medium height, 2224/72--branched white bearded of medium height, 1246/72--branched white beardless of medium height, and one four-rowed 2933/72--white beardless.

Laboratory trial II was set up in the same condition as trial I, but the analyses were carried out on 150 14-day old plants per genotype.

Lines derived from the cross Branched X vulgare have normally shaped heads, but contain the gene complex for branching (Koric, 1969, 1972).

Results

Laboratory Trial I

Of the 25 tested wheat genotypes, the largest number of primary rootlets (two-year average, 1973 and 1974) was recorded in Vigorka ($\bar{x}$ = 5.70), and the smallest number of rootlets in Centurk ($\bar{x}$ = 3.30) (Figures 1 and 2). Figure 1 shows that the majority of studied genotypes had an average of 4-5 primary rootlets. Very few genotypes had more than five primary rootlets. Similarly, very few genotypes had less than four primary rootlets.

To test the differences in the number of primary rootlets of the studied genotypes, the analysis of variance was made for two years (Table 1). The F-test established highly significant differences among genotypes (F-varieties = 11.29**). Highly significant differences also were recorded between years (F-years = 8.75**). The significance of differences between years is due to the very small trial error - 0.04.

Table 1. Analysis of variance for number of primary rootlets for two years of testing.

Source of variability	FG (n-1)	SQ		F
Total	49	12.24		
Year	1	0.35	0.35	8.75**
Variety	24	10.84	0.45	11.29**
Error	24	1.05	0.04	

** = differences significant at P = 1%

Laboratory Trial II

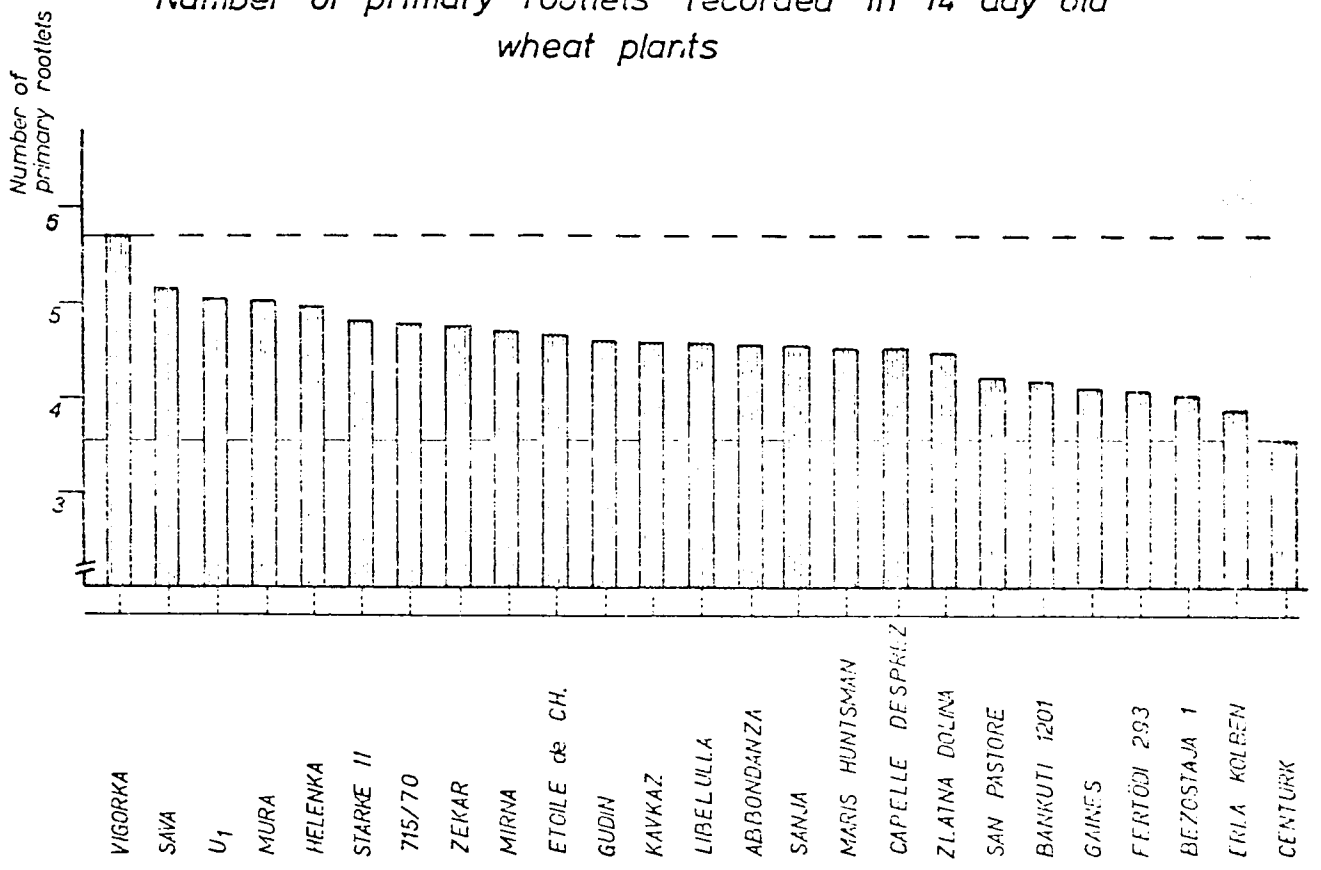
The largest number of primary rootlets was recorded in the normally shaped line with gene complex for branching (Branched X H303/1) X Branched ($\bar{x}$ = 5.48). It was followed by cultivar H303/1 ($\bar{x}$ = 5.43) (Figure 3). Cultivar Ranka was better than the line derived from the cross Branched X Ranka. Lines derived from the crosses Branched X Fiorello, Branched X Acciaio, and Branched X Ranaja had a larger number of primary rootlets than their parents of the vulgare type, but the differences were not statistically significant (Figures 4 and 5).

To test the differences in the number of primary rootlets of the genotypes, the analysis of variance was made for two years (Table 2). The differences between years are not significant, whereas the differences between varieties are significant at P = 5%.

** = differences significant at P = 1%
* = differences significant at P = 5%

Fig. 1

Number of primary rootlets recorded in 14 day old wheat plants



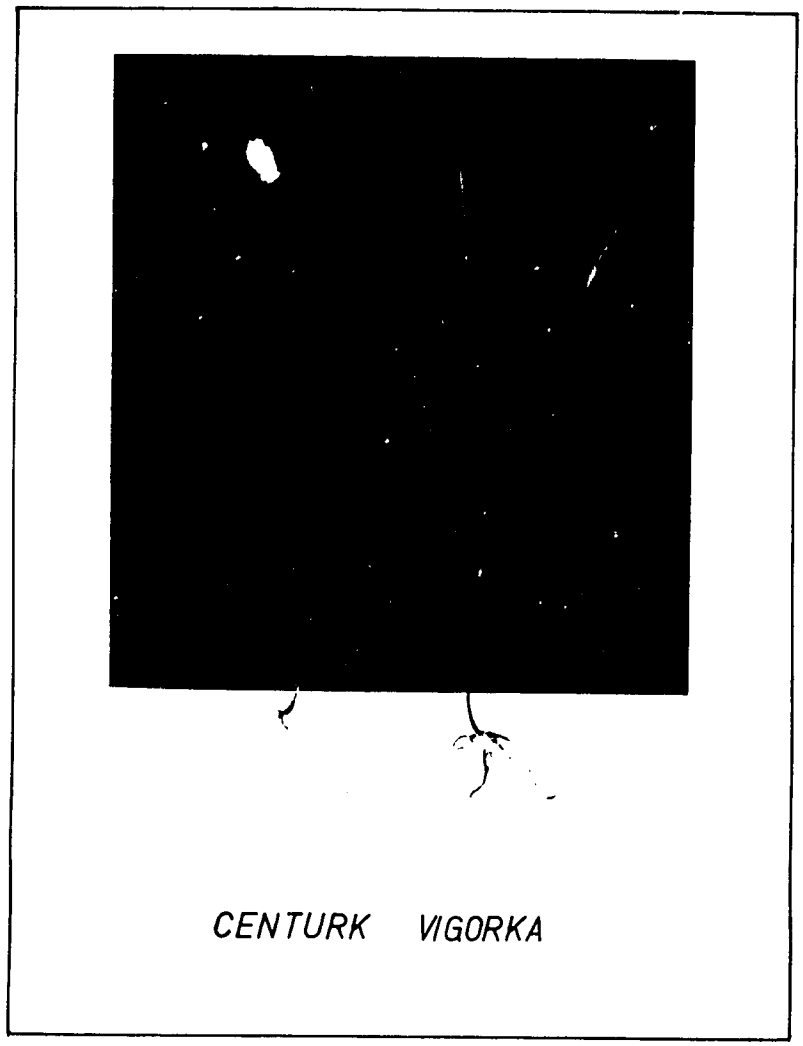


Fig. 2 Number of primary rootlets recorded in 14-day old wheat plants of cultivars: CENTURK and VIGORKA

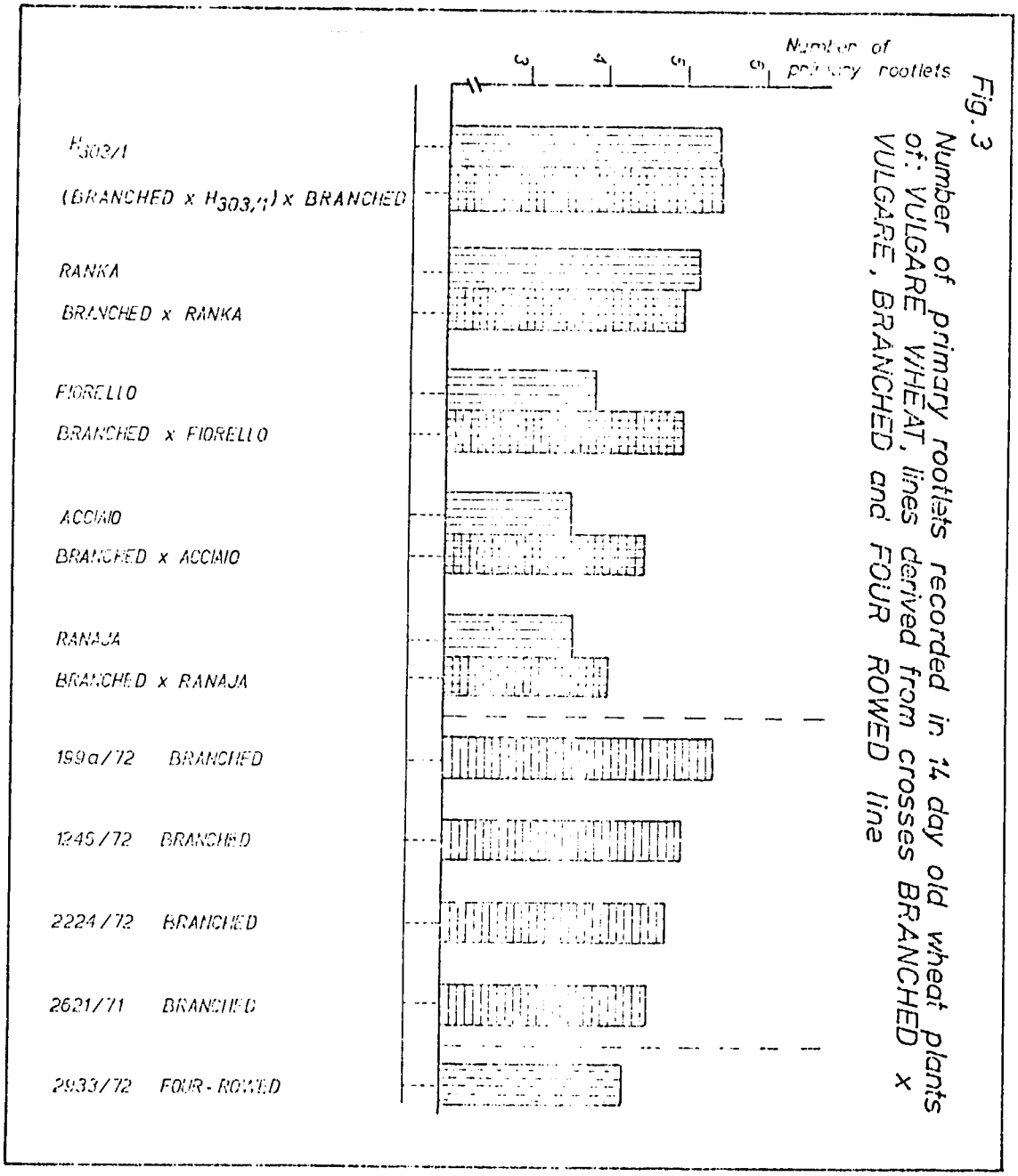


Fig. 3

Number of primary rootlets recorded in 14 day old wheat plants of: VULGARE WHEAT, lines derived from crosses BRANCHED x VULGARE, BRANCHED and FOUR ROWED line

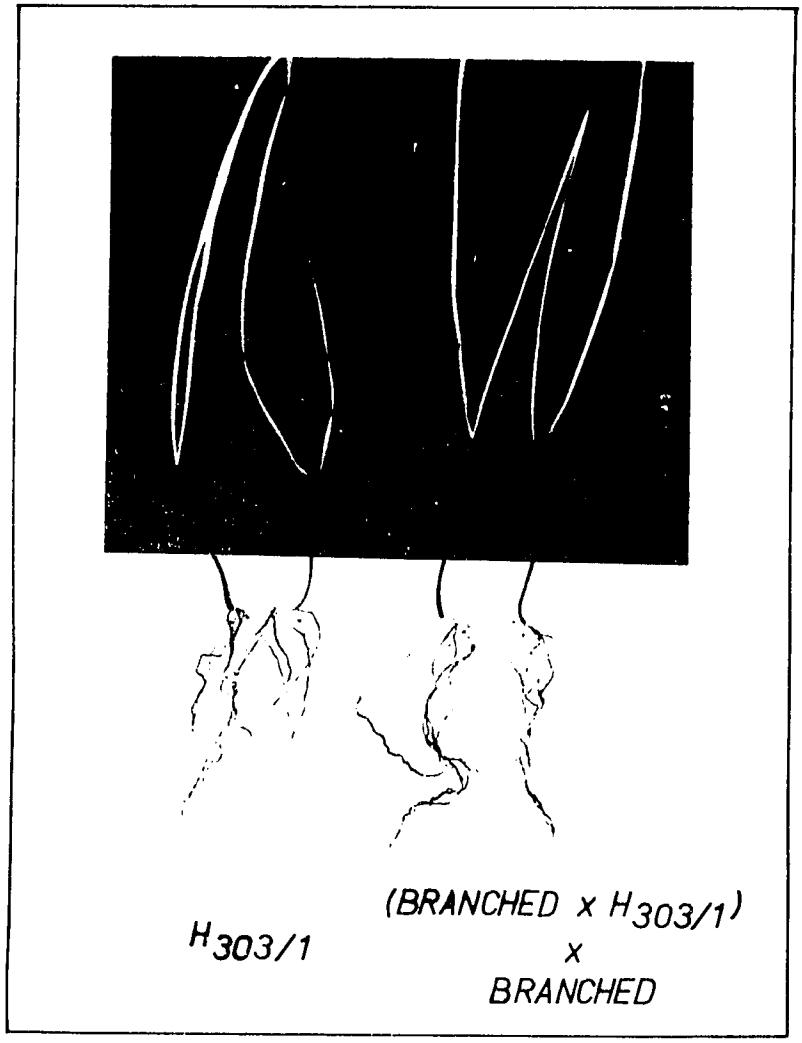


Fig.4 Number of primary rootlets recorded in 14-day old plants of wheats: $H_{303/1}$ and line derived from cross (BRANCHED x $H_{303/1}$) x BRANCHED

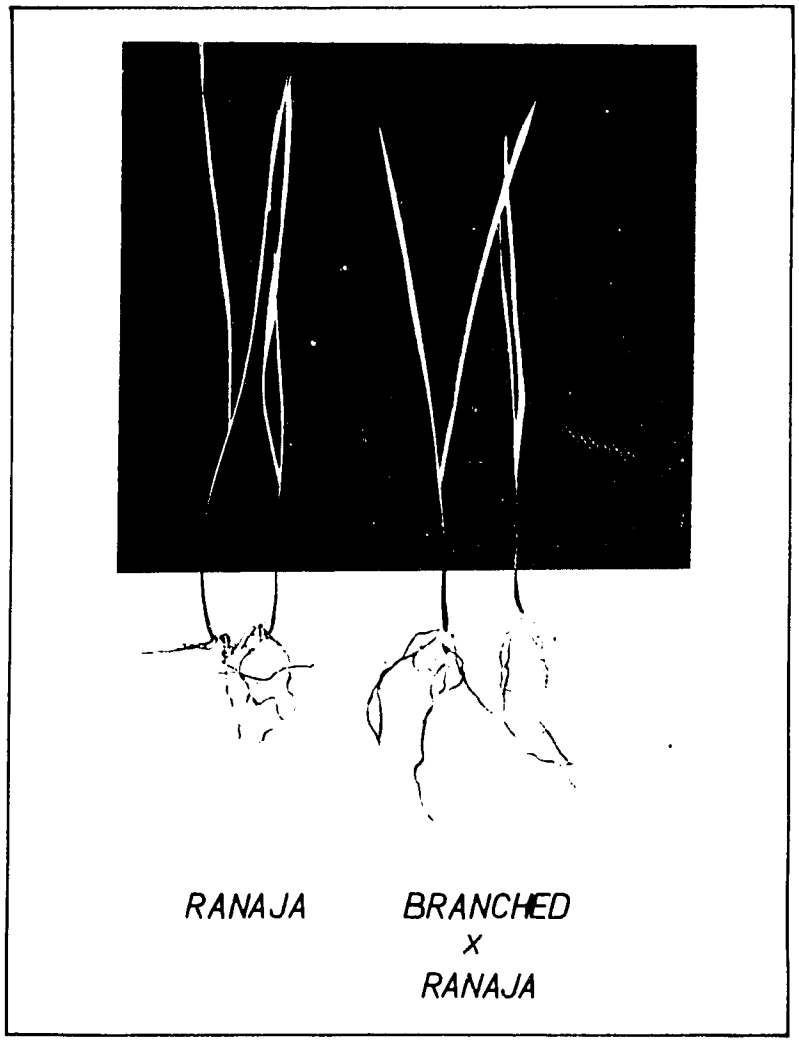


Fig.5 Number of primary rootlets recorded in 14-day old wheat plants of RANAJA and line derived from cross BRANCHED x RANAJA

Table 2. Analysis of variance for number of primary rootlets for two years of testing.

Source of variability	FG (n-1)	SQ		F
Total	29	17.70		
Year	1	1.02	1.02	3.00
Variety	14	11.86	0.85	2.50*
Error	14	4.82	0.34	

* = differences significant at P = 5%.

No significant differences were established between branched lines. The largest number of primary rootlets was determined in the branched selection 199a/72 ($\bar{x}$ = 5.41) and the smallest number of primary rootlets in selection 2621/71 ($\bar{x}$ = 4.63).

The four-rowed line 2933/72 displayed large differences in the number of primary rootlets in the two investigation years.

Discussion

The number of primary rootlets is an important quantitative character of the wheat root. It should be pointed out that there are large differences in the number of primary rootlets in wild forms and in extensive and highly intensive wheat genotypes. Extensive types have a considerably smaller number of rootlets than the cultivated ones. However, cultivar U_1 is an exception for it is characterized by a large number of primary rootlets in spite of its being taller and lower yielding than the very intensive genotypes of today. Still, the statement applies to the other genotypes mentioned (Bankuti 1201 and others).

The stalk height of the genotype and the number of primary rootlets are in negative correlation (Kuburovic, 1971). In this work, H303/1 and the line derived from the cross Branched X vulgare, (Branched X H303/1) X Branched, were tested. Both are of greater height and have the largest number of primary rootlets.

The number of primary rootlets is an important indicator of the expression of the characters of the adult organism which effect the yield. The number of primary rootlets is in positive correlation with the principal elements of yield structure. These essential statements were confirmed by a number of authors (Kuburovic, 1971; Mac Key, 1973; Velsovskaja, 1970, Tavcar and Kendjelic, 1969, and others). The greater the number of primary rootlets the more productive and stronger will be the plants that develop (Kandaurov, 1969; Pelcih, 1969).

Conclusion

Laboratory trials (trials I and II) relating to the number of primary rootlets point to the following conclusions:

1. Highly significant differences in the number of primary rootlets were recorded in 25 wheat genotypes tested in trial I. The largest number of primary rootlets was that of the Vigorka variety ($\bar{x}$ = 5.70), and the smallest in the Centurk variety ($\bar{x}$ = 3.30).

2. Of the 15 genotypes tested in trial II (lines derived from the cross Branched X vulgare, their parents of the vulgare type and a four-rowed line) a significant difference was established at P = 5% for the number of primary rootlets.

3. In lines derived from the cross Branched X vulgare, the largest number of primary rootlets was determined in the line of normally shaped head with gene complex for branching (Branched X H303/1) X Branched ($\bar{x}$ = 5.48), and the smallest number in the line Branched X Ranaja ($\bar{x}$ = 4.34) which is in accordance with the parent genotypes, because H303/1 had the largest and Ranaja the smallest number of primary rootlets.

4. In branched lines, the largest number of primary rootlets was recorded in the dwarf highly branched selection 199a/72 ($\bar{x}$ = 5.41) and the smallest number of primary rootlets in the semi-dwarf line 2621/71 ($\bar{x}$ = 4.63). There were no significant differences in the number of primary rootlets between branched lines. The four-rowed line 2933/72 displayed a large difference in the number of primary roots in two investigation years.

5. Branched lines and the four-rowed one had a larger number of primary rootlets than the common genotypes of the vulgare type at the significance of P = 5%. Consequently, the branching gene complex seems to have an influence on the development of a larger number of primary rootlets.

6. No significant differences in the number of primary rootlets were established among lines derived from the cross Branched X vulgare, nor between the branched and the four-rowed line. Similarily, there were no significant differences in the number of primary rootlets between lines derived from the cross Branched X vulgare and their parents of the vulgare type, although the lines from the cross Branched X vulgare had a larger number of primary rootlets.

7. In the course of the investigations it was realized that the number of primary rootlets can speed up the process of wheat breeding by means of allowing discard of superfluous genotypes.

References

Kandaurov, V. I. and A. V. Nefedor. 1969. Primary roots as a selection character in spring wheat breeding. Plant Breeding Abstract 39. p. 6425.

Kiricenko, F. G. 1969. Otbor selskonozjajstvenih rastenij po moscnosti razvitija kornevoj sistemi v celjah selekciji i semanovodstva. Vestnik selskohozjajstvenoj nauki. No. 12:135-136. Moskva.

Koric, S. 1969. Iskoristavanje granatog genskog kompleska za povecanje produktivnosti kod psenice Triticum aestivum spp. vulgare. Novi Sad, Savremena poljoprivreda.

Koric, S. 1972. Geneticka analiza faktora granatosti kod Triticum aestivum spp. vulgare i Triticum turgidum, te interakcija faktora granatosti na ostali genski kompleks speciesa Tritcum aestivum. Finalni izvjestaj ITC Projekta R-30-Cr-23.

Kuburovic, M. 1971. Korenov sistem nekih genotipova psenice u pocetnom stadiju razvoja u odnosu na vaznija svojstva odraslih biljaka. (mag. radnja).

Mac Key, J. 1973. The wheat root. Proc. 4th Intern. Wheat Genetics Symposium, Missouri, USA.

Manner, R. 1965. The number of seminal roots in certain species of wheat. Plant Breeding Abstract, Vol. XXXV, No. 3.

Pelcih, I. L. 1969. Root system and productivity of wheat. Plant Breeding Abstract 39. p. 6426.

Ravenska, B. 1965. Uber die Keimwurzelanzahl bei Weizen Biologia Plantarum, Praha 7/1:79-80.

Saric, M. 1952. Uticaj apsolutne tezine semena na broj primarnih korencica kod zita. Arhiv bioloskih nauka 1-2.

Velsovskaja, L. A. 1970. Produktivnost jarovo psenici v zavisimosti od kolicestva kornej. Zbornik trudov aspirantov i molodih naucnih sotrudnikov 17:42-49. Leningrad.

Tavcar, A. i V. Kendjelic. 1969. Razvoj korenja na 14 dana starim biljcicama psenice u odnosu na neka korisna svojstva odraslih biljaka. Savremena poljoprivreda, XVII No. 11-12, Kragujevac, 9-11, VI.

ATTEMPTS TO BREED SMALL GRAINS FOR INCREASED DROUGHT RESISTANCE

D. Atsmon
Israel

Abstract

Most of the small grain area in Israel is in the South where annual precipitation (during the winter only) is in the 250-350 mm range and evapo-transpiration is high. Therefore, water stress is a constant threat and strikes mostly after emergence and/or at grain filling. A search for genetic sources of avoidance included variety screening for rapid root growth, water-saving stomatal behavior, and earliness.

Rate of root growth, as measured by uptake of 32 P from various depths, was directly correlated with earliness and generally was faster in barleys as compared to wheats. Stomatal behavior (in potted plants) was largely affected by soil moisture, even within the range of field capacity, thus obscuring and over-riding any possible genetic variation in that respect. Earliness was found beneficial when water stress develops in spring, but found to be negatively correlated with yielding potential; therefore, extreme earliness is considered undesirable.

A totally different approach involves the usage of desert-growing wild relatives of wheat as possible donors of drought resistance to common wheat. A physiological and biochemical comparison between experimentally water-stressed *Triticum aestivum*, *T. longissimum*, and *T. kotschyi* led to the following results:

a) *T. kotschyi* significantly deviated in all parameters checked from the other two species.
b) On the level of the intact plant, leaves of *T. kotschyi* maintained higher relative water content, greater stomatal aperture and higher rate of CO_2 fixation at leaf water potentials which already caused a sharp decline of these parameters in the other two species.
c) Chloroplasts isolated from water-stressed plants showed a sharp decline in rates of electron transport and photophosphorylation at significantly lower water potentials for *T. kotschyi* as compared with the other two species.
d) A similar picture to that described above in (c) was found for the levels of *in vitro* activities of the two main carboxylating enzymes RUDP case and PEP case. Moreover, the gradually developing water-stress induced in only *T. kotschyi* an initial increase in the activity of PEP case.

These results suggest that *T. kotschyi* possesses a mechanism (osmoregulation? compartmentization?) which enables the plant to carry on dry matter production at lower water potentials, as compared to the two other species. The possible exploitation of this characteristic in a breeding program will be discussed.

The Weizmann Institute of Science, Rehovot.

LIFE CYCLE AS A BREEDING GOAL IN RELATION TO SOME OTHER TRAITS OF WHEAT AND WHEAT PRODUCTION IN YUGOSLAVIA

Zdravko Martinic-J.
Yugoslavia

Abstract

The optimal life cycle of a common wheat for a given region depends not only on climatic conditions of the region but also on the cultural practices by which man, as producer, tries to influence the wheat environment as a whole. Therefore, the optimal life cycle of most successful varieties for a given region is a changeable phenomenon. Such an obvious change of the life cycle of varieties has taken place in the last 25 years in Yugoslav wheat production.

The life cycle of varieties introduced in Yugoslav wheat production 25 years ago, unlike the life cycle of new Yugoslav varieties now predominate in production, is about a week earlier than the currently grown varieties in this region. At the same time, the new varieties are much higher in yield potential than traditional varieties being about a week later maturing.

The fail rule of the life cycle (maturity) of new successful varieties in Yugoslav wheat production is expressed in the fact that they all fail in the same maturity group. As a consequence, the optimal harvest time is very short. However, in the crosses of Yugoslav breeding programs, there are introduced varieties which are as much as eight days earlier as well as up to 14 days later in heading time than varieties with the optimal maturity for the present Yugoslav wheat production environment.

Because of the large genetic variability of this trait introduced in the crosses and because of the achieved recombination of high yield and resistance to diseases in new Yugoslav lines, it is realistic to expect in the near future new successful varieties with high and stable yields which will be much different in life cycle than currently grown varieties. However, it seems to be easier to breed new later-maturing than earlier-maturing varieties compared with the varieties which are now widely grown in Yugoslavia. The obvious progress in the direction of earliness without a loss in the yield seems to be less credible, although surprises in plant breeding are always present.

For further quick improvement in both directions, the open international and national cooperation and exchange of information and material is of utmost importance.

Faculty of Agricultural Sciences, University of Zagreb.

Introduction

The life cycle of common wheat, like that of other small grains, is a complex trait. Almost all environmental factors especially temperature, supply of water and fertilizers, day length and the quality of the light are of special importance for expression of this trait. The vernalization requirement of winter wheats and the day length in spring and winter varieties have, at least in some varieties, almost a qualitative effect on the duration of the life cycle of varieties.

A generally accepted opinion is that, in each wheat producing region, there are varieties with a definite length of life cycle which are most adapted and suitable to the environmental conditions of that region.

However, the life cycle of new varieties in comparison with the previous ones is changing in the course of time in many wheat producing regions of the world. This change is taking place in conjunction with changes in some environmental factors which have been and are considerably influenced by man. Such change in life cycle of varieties has taken place during the last 25 years in Yugoslav wheat production. The new Yugoslav varieties, now widely spread in Yugoslav production, are not only a week earlier, but at the same time, they also are higher in yield than varieties previously grown in this region.

Life cycle in relation to the yield in production.--There are two important things which a wheat breeder has to take into account when he is planning the life cycle of varieties: 1) the height of yield and 2) the duration of the harvest.

The yield of a new variety should be the highest possible for a given region with the shortest life cycle possible, which can be called the optimal life cycle for that region. However, the optimal life cycle of a given region is a changeable phenomenon. It is changing not only in conjunction with the changes in environmental factors like water, fertilizer supply or others, but also in conjunction with the introduction of new genes in wheat breeding programs which makes possible new, more suitable combinations of genes in new lines,i.e. future varieties.

On the big farms in Yugoslavia, some of which sow up to 20,000 ha of wheat per year, it would be important to have varieties which differ in life cycle to such an extent that the harvest time can be prolonged as much as possible without loss in yield quantity or quality.

On the other hand, an extra early variety could be of special interest for the production of two crops in the same year, especially in regions where shortage of land is a problem of primary importance. However, extra early lines or varieties usually give lower yields than varieties with an optimal life cycle. Our late-maturing varieties are exposed in Yugoslav growing conditions to a

stronger attack of diseases and to higher temperatures than early-maturing varieties. Although late varieties often give in micro-trials the same or even higher yields than early-maturing varieties, they are hardly successful and approved in commercial production in this region.

Table 1 shows the relative number of days to heading of different wheat varieties. If we take as a criterion of life cycle of varieties the number of days to heading, then the life cycle of the variety Libellula, with a tolerance of ± 2 days, should be marked as the optimal life cycle of varieties in present Yugoslav wheat breeding and production. As a matter of fact, the widely spread varieties in modern Yugoslav wheat production were the Italian varieties San Pastore and Libellula. The two Yugoslav varieties which successfully replaced them in production i.e. varieties Sava and Zlatna Dolina, as shown in Table 1, are very close in heading time to Libellula.

Table 1. Life cycle of different wheat varieties expressed as relative number of days to heading in relation to variety San Pastore.

Variety	Days to heading ± San Pastore	
Inia/Mex/	- 8.5	
Akakomugi/J/	- 4.7	
N. Rana 1/Yu/	- 0.3)	
S. Pastore/I/	0.0)	The optimal life cycle in modern wheat production in Yugoslavia.
Libellula/I/	+ 1.0)	
Sava/Yu/	+ 1.7)	
Z. Dolina/Yu/	+ 2.7)	
Bezostaja 1/USSR/	+ 5.2	
Bankuty 1205/H/	+ 6.0)	The optimal life cycle in traditional wheat production in Yugoslavia.
U - 1/Yu/	+ 7.0)	
Nord Desprez/F/	+ 14.0	
Heine VII/G/	+ 14.0	

It is obvious that Yugoslav wheat breeders have on their disposal rather big genetic variability in the directions to earliness (Inia 66) and to lateness (Heine VII) not yet incorporated in new successful varieties.

Inia 66, a spring wheat of Mexican origin, when fall-sown in the Zagreb environment, heads an average 9.5 days earlier than Libellula and 3.8 days earlier than the Japanese variety Akakomugi from which Libellula and other Strampelli-type varieties inherited their earliness (Strampelli 1932, Vienhues 1961). On the other hand, there are varieties which head 14 or more days later than Libellula (Table 1).

It is obvious that Yugoslav wheat breeders have at their disposal genetic variability in the direction of earliness (Inia 66) and of lateness (Heine VII). Because of the use of harvest machines and life cycles of current basic varieties which are very similar, the big wheat producers in Yugoslavia are willing to accept every

new variety with higher, or even the same, and more stable yield. These would be earlier or later (5 or more days) than the basic varieties in production. Extra-early varieties would be of interest for the production of two crops in the same year, at least in some regions.

Optimal life cycle in relation to vernalization requirement and photoperiodism of varieties.--The optimal life cycle of widely grown varieties in Yugoslav wheat production is shorter by 5-7 days than it was in varieties previously grown in this region. What about the vernalization requirement and response to photoperiod of new early varieties in relation to traditional ones?

As shown in Table 2, the most successful new Yugoslav varieties do not differ considerably in vernalization requirement in relation to varieties previously grown in this region, but they do differ essentially in response to day length. The new Yugoslav varieties like Zlatna Dolina and Sava show low response to shortened photoperiod of 11.30 hrs (Martinic, 1971) and they delay development and heading under these conditions much less than the varieties Bankuty 1205 or U-1 previously grown in this region (Table 2).

Table 2. Vernalization requirement and response to photoperiod of varieties.

Variety /abbreviation/	Heading ± S. Pastore days	Vernalization requirement Type	Vernalization requirement Days	Response to shortened Days	Response to shortened Type
Akakomugi/J AK/	- 4	IIb	0	+ 6.8	L
S - 1 /S-1/	- 3	I	0	+ 5.4	L
Abbonda NCA/Abb/	+ 2	IIb	0	+ 6.9	L
Newthatch/NT/	+ 5	I	0	+ 27.7	L
S. Pastore/SP/	+ 0	IVa	40	+ 5.0	L
Libellula/Lib/	+ 1	IVa	40	+ 6.7	L
Z. Dolina/ZD/	+ 3	IVc	40-50	+ 7.9	L
Sava/SV/	+ 2	IVa	40	+ 5.0	L
Bezostaja/Be-1/	+ 5	IVc	40-50	+ 6.4	L
Etoile de/ET/ Choisy	+ 5	V	60	+ 9.3	L
Bankuty 1205/B-1205/	+ 6	IVc	40-50	+ 29.5	H
U - 1/U-1/	+ 7	IVb	40-50	+ 29.0	H
Nord Desprez/ND/	+ 14	IVb	40	+ 24.0	H
Heine VII/H-VII/	+ 14	VI	60	-----	H

- Heading relative to variety S. Pastore, fall sown.
- Vernalization requirement in days for uniform heading in spring sowing.
- Response to photoperiod expressed as the delay of heading of variety in days when sown in spring with vernalized seeds and grown for 50 days in shortened photoperiod of 11.30 hrs. L=low, H=high responding variety.

On the contrary, S. Pastore, Zlatna Dolina, Sava and similar varieties have a well expressed vernalization requirement which is essential for their adaptation to early and normal fall sowing time in Yugoslavia (Figure 1). The winter varieties with vernalization requirement similar to that of S. astore, although relatively non-responsive to shortened photoperiod, can be sown at the normal fall sowing time without danger of entering the generative stage before the onset of winter (Martinic, 1969). In the winter time development is controlled by the low winter temperatures which slow down growth and development at the same time.

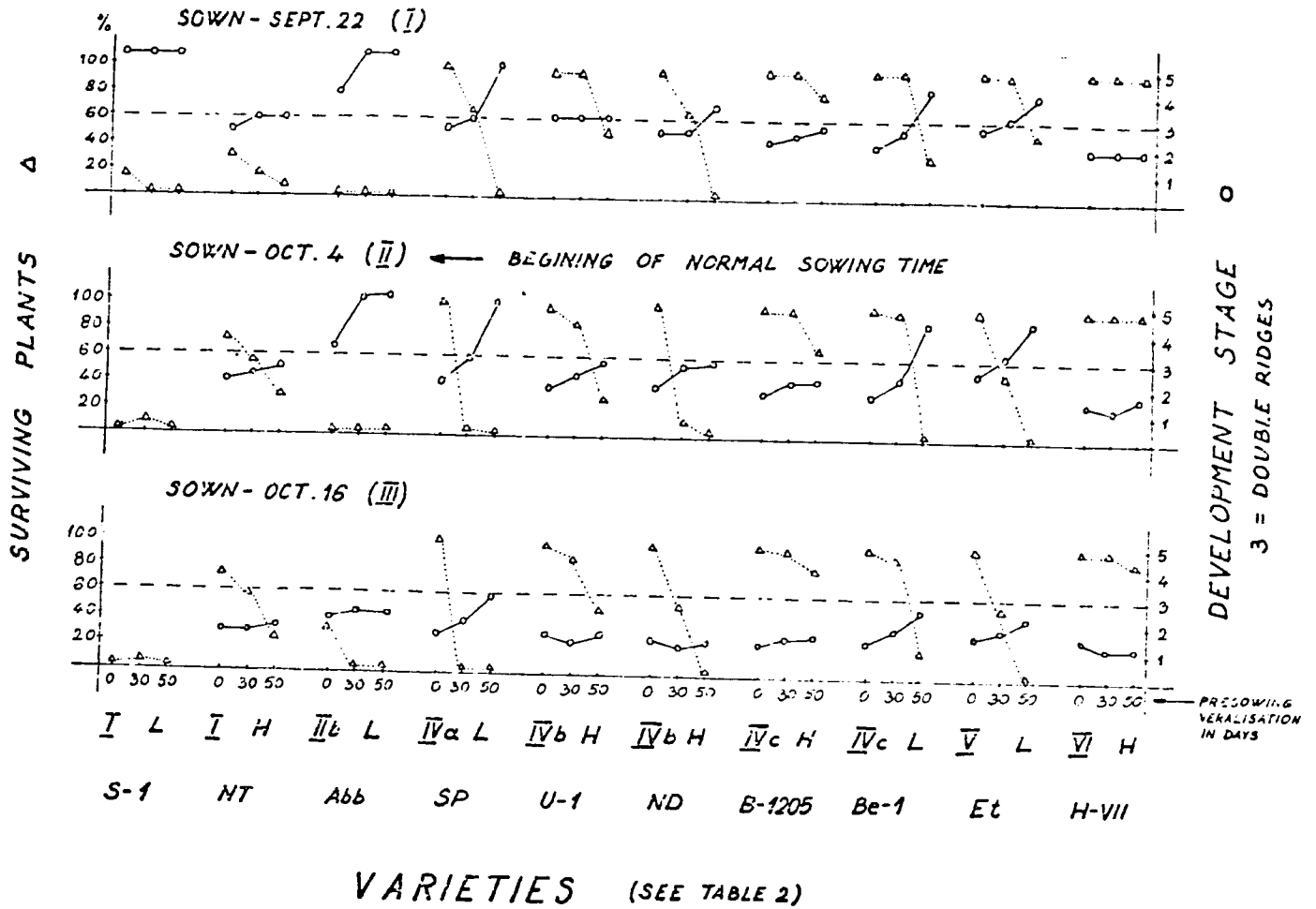
We were able to demonstrate (Martinic, 1975) a low correlation coefficient (r=0.201) between relative number of days to heading in fall sowing and the response to shortened photoperiod of varieties. A number of varieties with high and low response to photoperiod headed about the same time under normal fall sowing conditions in Zagreb environment.

Response to photoperiod and earliness in relation to yield and yield stability.--A question of theoretical importance is how it is possible that early-maturing varieties are higher in yield than late-maturing ones when grown in the same region.

The successful early-maturing varieties are usually varieties with short straw (semidwarfs or dwarfs). This characteristic and probable additional special genes allow them to develop more heads per growing area and a more suitable harvest index, which favors more grain production by the same straw production. However, it was demonstrated (Borojevic, 1978) that Sava, a high yielding, early maturing variety with low response to photoperiod represents progress in Yugoslav wheat breeding, not only in grain yield, but also in total dry matter production, when compared with varieties which it replaced in the commercial production. The other reason for higher grain yield of varieties with low response to photoperiod in comparison with high response ones is the fact that low response varieties have the same or even a longer generative stage than varieties with high response to photoperiod.

It is very probable that varieties with low sensitivity to daylight respond especially well to temperatures suitable for growth in late winter time (February - March) when the natural day length is shorter than 12 hours. In such years, which are rather frequent even within the bounderies of the Mediterranean region, the low sensitivity to photoperiod seems to be essential for the high and stable yield. However, the influence of response to photoperiod to the yield and yield stability seems to be very hard to separate from the influence of expression of other traits to the grain yield of a variety. When separation of the influence of low sensitivity to photoperiod from influence of other traits to yield and yield stability cannot be made, it is not possible to measure separately and directly the magnitude of this influence.

However, there remains indirect proof of importance of this trait which is evident in the fact that low response to photo-



VARIETIES (SEE TABLE 2)

FIGURE - 1

period is now a standard characteristic of all new Yugoslav varieties now in successful production, even though special breeding methods for the trait have not been applied in breeding procedures in Yugoslavia (Martinic, 1971). A consequence of the breeding for high and stable yield has by itself, led to the selection of lines with low sensitivity to daylight in all wheat breeding programs in Yugoslavia.

Life cycle of varieties in relation to Yugoslav environmental conditions.--Varieties accepted now in modern Yugoslav wheat production are early maturing varieties with low response to photoperiod and with medium expression of the vernalization requirement. However, the most successful varieties do not differ enough in life cycle. It is obvious that some climatic and biotic factors limit the life cycle of the most successful varieties to some definite development pattern which is most suited to the present state of agroecological factors of wheat production in Yugoslavia.

Genes for earliness are introduced in Yugoslav wheat breeding programs and earliness is generally accepted as an important trait for yield stability in this region. The early maturing varieties are not exposed, like the late ones, to the attack of plant diseases, especially to stem rust which was in the past a limiting factor in wheat production in the western part of the country. They also are less frequently exposed to high temperature stresses in the eastern part of the country. In spite of this, no one has yet succeeded in breeding a new successful variety which would be 5 or more days earlier than the Italian variety S. Pastore. It remains an open question how it would be possible to compensate the shorter duration of assimilation surface during the entire life cycle and especially during the period from heading to maturity in varieties earlier than San Pastore. Cool, wet and cloudy weather is frequently present at the time of heading of extra-early varieties and it can represent a serious barrier to the yield potential and yield stability of these varieties i· Yugoslav growing conditions. Therefore, it seems to be easier to breed new later rather than new earlier varieties as compared with those now predominant in Yugoslav wheat production. This idea may have been followed also by the USSR breeder Lukjanenko when he bred for the Krasnodar region the varieties Aurora and Kavkaz which were later than variety Bezostaja 1. However, Aurora and Kavkaz, although being varieties with low sensitivity to photoperiod, were better accepted in regions more northern than Krasnodar or Yugoslavia.

Late maturing varieties should be resistant or at least highly tolerant to diseases, especially to stem rust. This resistance or tolerance should be more stable or durable than in early varieties. In addition, late varieties for Yugoslav growing conditions should be tolerant to high temperatures which frequently occur especially in the eastern part of the country. Etoile de Choisy was discarded from Yugoslav production at the beginning of its production because it did not withstand the stress situation of high temperatures in the eastern part of the country in 1964. The non-suitability of Aurora and Kavkaz for the main wheat-producing area in Yugoslavia has to be ascribed primarily to their lateness for Yugoslav growing conditions.

Discussion and Conclusions

The optimal life cycle of varieties for a given region is changing over time with the changes in environmental factors cause by man and with the new combinations of genes in new varieties.

The optimal life cycle of varieties in the present Yugoslav wheat breeding and production situation should be considered the life cycle of the variety Libellula with a tolerance of ± 2 days. However, this is inconvenient because the optimal harvest time for the varieties with very similar life cycles is too short. However, extra-early varieties as well as late ones, although in microtrials can have the same or even higher yields than varieties now predominant in production, do not show the same yield potential and yield stability in commercial production.

In spite of this, some improvement in the direction of earliness and lateness can be expected in the near future because of extensive genetic variability which has been introduced in crosses and because of the results achieved up to now in recombination of genes for high yield potential and for resistance to diseases in new lines. It seems, however, that it would be easier to breed a new successful late variety than an extra early variety when one crop system is involved.

It should also be pointed out that unpleasant surprises in plant breeding, in spite of the much progess achieved in this field as a whole, are frequent in each program and, these surprises we have to anticipate in advance. Unpleasant surprises will be more rare as wheat breeding becomes a more applied science and less an applied art. For quick further improvement, however, it is of utmost importance to stimulate open cooperation and exchange of the research data and genetic material on the national and international levels.

References

Borojevic, S. 1978. Can we develop varieties and races as we model them? XIV International Congress of Genetics, Moscow, 21-31. Aug. 1978.

Lukjanenko, P. P. 1973. Izabranie trudi, Moskva, Kolos.

Martinic, Z. 1969. Ozimost, razvoj i prezimljenje sorti psenice slabe reakcije na fotoperiod kod ranih rokova jesenske sjetve. Savremena poljoprivred, br. 11-12, 183-192.

Martinic, Z. 1971. Low response to photoperiod as a standard characteristic of new Yugoslav high-yielding common wheat varieties. Eucarpia, Proc. Dijon 1971, 123-134. St. Amel. Pl. BV 1540-21, Dijon, France.

Martinic-J., Z. 1975. Life cycle of common wheat varieties in natural environments as related to their response to shortened photoperiod. Z. Pflanzenzucht. 75: 237-251.

Vienhues, F. 1961. Fruhreife und Ertrags bildung beim Weizen in Abhengigkeit von der entwicklungs physiologischen Veranlagung und den Klimafaktoren licht und temperatur. Z. Pflanzenzucht, 46: 45-66.

CHROMOSOMES, GENES, PROTEINS AND WHEAT ENDOSPERM

F. Garcia-Olmedo and P. Carbonero
Spain

Summary

Data on the redundancy and expression levels of genes encoding wheat endosperm proteins are discussed in connection with their evolution and with the evolution of reserve proteins in other cereal crops. The molecular basis of the D-genome contribution to baking quality are analysed in terms of proteins and lipids.

Introduction

Our research group has been involved for some years in a study of the genetic control of the biochemical composition of wheat endosperm. The purpose of this contribution is to review those aspects of this work that are related in a general way to both the nutritional and the technological quality of wheat.

To a great extent, the genetic analysis has been made possible by the development of a great variety of aneuploids, which was pioneered by E. R. Sears (1,2). It should be pointed out that with aneuploids, the genetic analysis only goes down, at most, to the level of large chromosomal segments and that to actually deal with genes, data on segregation of allelic variants is required. These data are mostly lacking in the case of endosperm biochemical characters. In the case of some major protein components, this lack has been compensated in part by a thorough characterization of the gene products, but in the case of regulatory or quantitative effects, aneuploid analysis does not allow to discriminate between single gene and whole chromosome. Furthermore, it is often difficult to distinguish between true chromosomal effects on the level of expression of a certain biochemical character and the indirect consequences of deleting large segments of genetic information. In other words, it is difficult to tell apart relevant information about the regulation of gene expression from irrelevant, non-specific, drastic effects brought about by large deletions.

With these considerations in mind, we have chosen to discuss two specific aspects of the general topic which are respectively related to the nutritional and the technological quality of wheat: i) the genetic control of wheat endosperm proteins; and ii) the contribution of the D genome to baking quality.

Redundancy and Expression Levels of Genes Encoding Endosperm Proteins

Breadwheat (*Triticum aestivum* L., genomes AABBDD) is an allohexaploid in which most of its genetic information must have been triplicate when the species originated. Our early observations on

Department of Biochemistry, E.T.S. Ingenieros Agronomos, Madrid.

the distribution of certain biochemical systems among species of the Aegilops-Triticum group suggested that redundant genetic expression is partially lost after poliploid formation (3,4). Subsequently, this phenomenon has been well demonstrated both in animals (see ref. 5) and in plants (6).

Data on the chromosomal location of genes that control different biochemical systems, obtained by aneuploid analysis in several laboratories, including ours, permit not only the estimation of the percentage of gene triplication and duplication expressed, but also to discern where the presumed "losses of redundacy", or inactivations, have taken place. We have carried out such a survey (6) and out of 28 sets of homoeologous systems, 16 were controlled by triplicate loci, 7 by duplicate loci, and 5 by single loci (Table 1). The proportions of silenced loci turned out to be different for each genome. A (32%) > B (18%) > D (11%). Most of the incomplete homoeologous sets were associated with major endosperm proteins with no apparent enzymatic function, whereas most of the enzymatic loci were triplicate (Table 1). This means, in practical terms, that the genetic systems for wheat endosperm proteins seem to be far more diploidized than the rest of the genetic information in wheat.

Table 1. Redundancy of genes encoding biochemical markers in wheat.

Redundancy	No of sets	%	Genomes A	B	D	Type of system
triplicate	16	57	+	+	+	Mostly enzymes
duplicate	7	25	+	+	-	
			+	-	+	Mostly endosperm
			-	+	+	proteins of presumed
single	5	18	+	-	-	reserve function
			-	+	-	
			-	-	+	
% silenced loci			32	18	11	

From a theoretical point of view it is of interest to speculate about the implications of such sharp contrast. Loss of redundant gene expression after polyploid formation is the simplest but not the only plausible explanation of our failure to observe triplicate loci for major endosperm proteins.

Alternatively, genes for some of the reserve proteins might have been silenced in some of the diploid species prior to the alloploid formation. This would imply that the expression of such genes might not be vital for the plant and their failure to express themselves could be compensated by an increased expression of genes encoding other non-homologous reserve proteins.

The fact that allopoid protein patterns can be often reconstructed by mixing in the test tube the diploid genome donors could be considered as evidence against the first alternative, since this would indicate that no extensive loss of expression of genes expressed in the genome donors could have taken place in the alloploid.

The second hypothesis could be further used to explain the striking diversity of reserve proteins among cultivated cereals. Most of these proteins do not seem to be as closely related from a structural point of view as would be expected of proteins encoded by genes derived from a close common ancestor, as is certainly the case for proteins with known enzymatic function. A model for the evolution of reserve proteins, based in the above is presented in Figure 1.

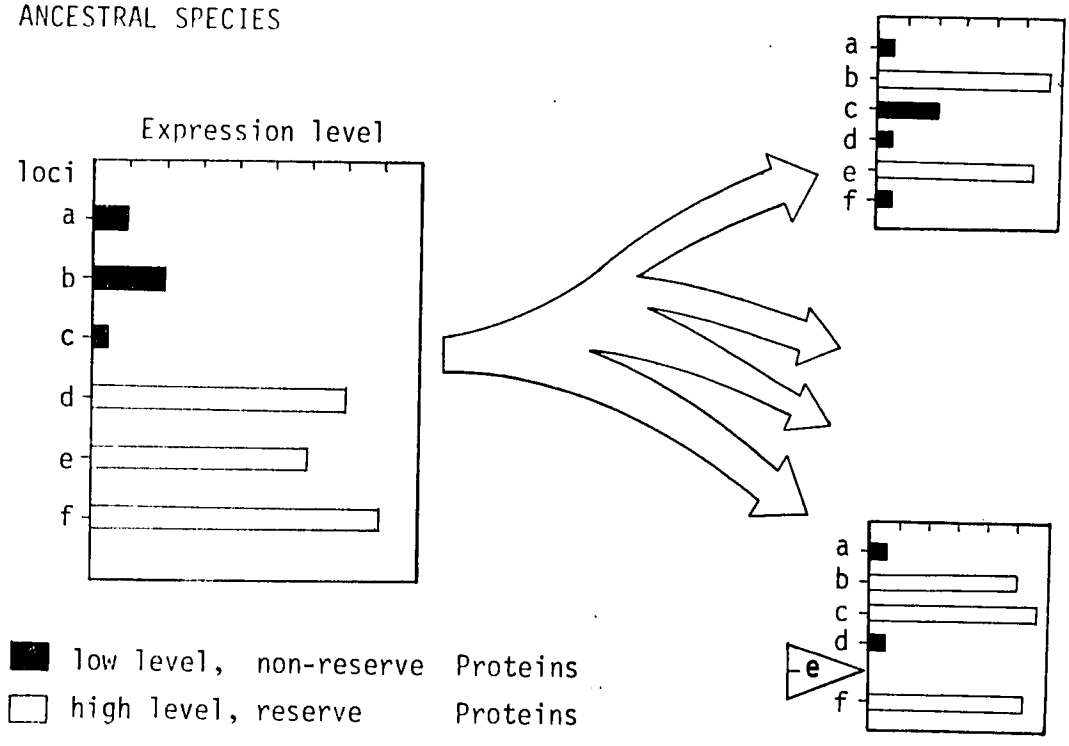


Figure 1. Model for the evolution of reserve proteins in cereal.

We have shown that the levels of certain individual protein components are strictly determined by gene dosage, while for other proteins, the net output at each dosage of its structural gene, can be 30-80% higher when the chromosome carrying an active homoeogene was absent (7). This is exemplified in Figure 2.

The amount of protein per gene dose, in the case of proteins of the first class, seems to be genetically determined, as has been shown in the case of the allelic pair CM3/CM3' (8). The amount of CM3 accumulated per gene dose, on a molar basis, is about twice that of CM3' (Figure 3). The genetic evidence indicates that the quantitative difference either depends on differences in the structural gene itself or is controlled by regulatory or modifier gene(s) linked to it.

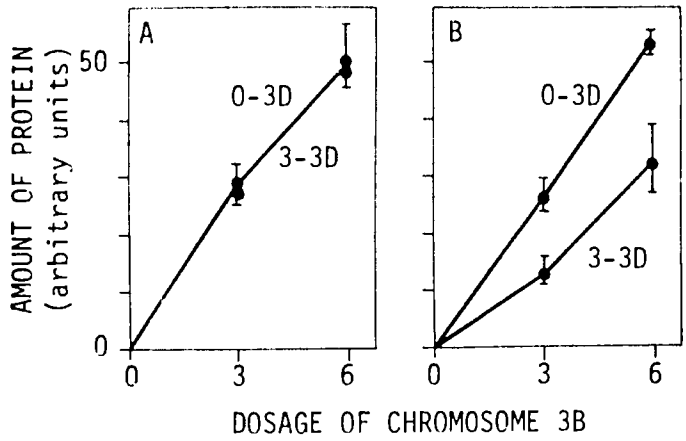


Figure 2. Gene-dosage responses of two proteins encoded by genes located in chromosome 3B. A) Protein in which gene-dosage response is not affected by chromosome 3D (presence or absence). B) Protein that is at a higher level in the absence of chromosome 3D, which carries a homoeogene (Data taken from ref. 7).

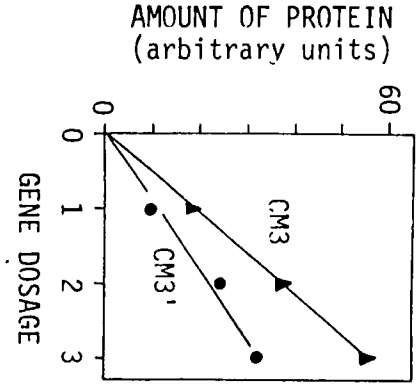


Figure 3. Gene-dosage responses of two allelic proteins, CM3/CM3' in T. durum endosperm. (Data taken from ref. 8).

The two cases just considered of alteration of gene-dosage responses would respectively represent examples of the short-term and long-term genetic mechanisms that would make possible the evolution of reserve proteins according to the model in Figure 1.

The well known high-lysine mutants described in other cereal crops can also be considered to reveal compensatory mechanisms of the type required by the model, as their effects can be interpreted as an enhancement of the expression of genes encoding certain lysine-rich proteins brought about by the partial blockade of the expression of genes encoding certain prolamines (zeins in maize, hordeins in barley).

Molecular Basis of the D-genome Contribution to Baking Quality

It is generally accepted that gluten proteins, gliadins and glutenins, play an important role in relation to baking quality and it has been assumed that the differences in baking quality between hexaploid and tetraploid wheats were mainly due to gluten proteins contributed by the D genome. Indeed, genes encoding gliadins and glutenins have been located in D-genome chromosomes by aneuploid analysis (see ref. 9).

The importance of wheat lipids in the above context has been often overlooked. Pomeranz and coworkers (10) found that bread volume was significantly decreased if "free" lipids were extracted from flour with petroleum ether. By adding back to the flour different fractions from the extract, it was found that the polar fraction was effective in restoring the original bread volume, whereas the non-polar was not. By subfractionation of the polar fraction, it was possible to identify digalactosyl diglyceride (DGDG) as the lipid class whose extraction determined the volume loss. Studies by infrared and nuclear magnetic resonance spectroscopy and by autoradiography seem to indicate that DGDG improves the retention of fermentation gases due to its ability to form hydrogen bonds with starch and gliadins and hydrophobic bonds with glutenins.

We found a sharp difference in the amounts of DGDG present in *T. aestivum* as compared with *T. durum* cultivars (Table 2, exp. 1). The extraction of the D genome from a hexaploid cultivar markedly decreased DGDG and the addition of the D genome to a tetraploid cultivar resulted in an enhanced DGDG level (Table 2, exp. 2). Finally, it was established by aneuploid analysis that a gene or genes located in the short arm of chromosome 5D was associated with the observed interspecific difference (Table 2, exp. 3).

These results strongly suggest that the addition of the D genome altered the baking properties of tetraploid wheats not only by altering their protein composition but also by drastically changing their polar-lipids profile (11).

Table 2. Relative contents of digalactosyl diglyceride (DGDG) in different wheat stocks.

Experiment no.	Stock	DGDG mm^2*	
1	T.aestivum cvs		
	Cabezorro	385	
	Pané 247	204	
	Chinese Spring	180	
	Aragón 03	176	
	Rieti	275	
	F.Aurora	282	
	Dimas	169	
	Ariana	88	
	Libero	172	
	Mara	173	
	Roma	196	
	Impeto	264	
			215 av.
	Composite flour A (37 cvs)	212	
	Composite flour B (5 cvs)	180	
	T.durum cvs		
	Hibrido D	12	
	Alaga	34	
	S.Capelli	72	
	Jerez 36	8	
	Andalucia	23	
			30 av.
	Composite flour C (5 cvs)	60	
2	Thatcher (ABD)	250	
	Tetra-Thatcher (AB)	45	
	Ae.squarrosa (D)	280	
	T.carthlicum (AB)	30	
	T.spelta (ABD)	190	
3	T.aestivum cv. Chinese Spring	185	
	ditelo 5DL	20	
	nulli 5D-tetra 5A	35	
	nulli 5A-tetra 5D	300	

*Densitometric determinations. Comparisons are valid within each experiment.

Final Remarks

Biochemists deal with specific molecules (proteins, lipids, etc.) and breeders try to manipulate global chemical composition either directly or through quality-related parameters. It is of interest to integrate both views. It is true that sometimes the trees do not allow to see the forest, but it is no less true, in our opinion, that proper management of the forest may require at times to pay attention to the individual trees. The present contribution is a modest and brief attempt of integration, taking examples from our own work as biochemists.

Acknowledgements

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References

1. Sears, E. R. 1954. The aneuploids of common wheat. Mo. Agr. Exp. Res. Bull. 572:1.
2. Sears, E. R. 1966. in: Chromosome Manipulations and Plant Genetics. p. 29. Ed. R. Riley and K. R. Lewis. Oliver and Boyd. London.
3. Garcia-Olmedo, F. 1968. Genetics of synthesis of β-sitosterol esters in wheat and related species. Nature 220:1144.
4. Carbonero, P. and F. Garcia-Olmedo. 1969. Purothionins in Aegilops-Triticum spp. Experientia 25:1110.
5. Ferris, S. D. and G. S. Whitt. 1977. Loss of duplicate gene expression after polyploidisation. Nature 265:258.
6. Garcia-Olmedo, F., P. Carbonero, C. Aragoncillo and G. Salcedo. 1978. Loss of redundant gene expression after polyploidization in plants. Experientia 34:332.
7. Aragoncillo, C., M. A. Rodriguez-Loperena, G. Salcedo, P. Carbonero and F. Garcia-Olmedo. 1978. Influence of homoeologous chromosomes on gene-dosage effects in allohexaploid wheat (Triticum aestivum L.). Proc. Natl. Acad. Sci. USA 75:1446.
8. Salcedo, G., C. Aragoncillo, M. A. Rodriquez-Loperena, P. Carbonero and F. Garcia-Olmedo. 1978. Differential allelic expression at a locus encoding an endosperm protein in tetraploid wheat (Triticum turgidum). Genetics 89:147.
9. Garcia-Olmedo, F., P. Carbonero, C. Aragoncillo and G. Salcedo. 1978. Chromosomal control of wheat endosperm proteins. A critical review in "Seed Protein Improvement by Nuclear Techniques" p. 555. International Atomic Energy Agency. Vienna.
10. Pomeranz, Y. 1971. Composition and functionality of wheat flour. In: Wheat Chemistry and Technology. Ed. Y. Pomeranz. American Association of Cereal Chemists. St. Paul.
11. Hernandez-Lucas, D., R. Fernandez de Caleva, P. Carbonero and F. Garcia-Olmedo. 1976. Control of galactosyl diglycerides in wheat endosperm by group 5 chromosomes. Genetics 85:521.

ALPHA-AMYLASE IN FIELD-SPROUTED WHEATS: ITS DISTRIBUTION AND EFFECT ON JAPANESE-TYPE SPONGE CAKE AND RELATED PHYSICAL AND CHEMICAL TESTS

K. F. Finney, O. Natsuaki, L. C. Bolte,
P. R. Mathewson, and Y. Pomeranz
United States

Abstract

To clarify the effect of field-sprouting on quality, we determined α-amylase activity (0 to 4.13 dextrinizing units; D.U./g) in typical field-sprouted (0 to 36.2%) soft white winter wheat composites and their mill fractions, and studied its effect on Japanese-type sponge cake and related tests. Average yields of the corresponding mill fractions of seven wheat composites were patent flour, 45%; midpatent flour, 10%; clear flour, 15%; bran, 25.8%; shorts, 3.2%; and red dog, 1.0%. Ash and protein contents of the fractions were typical. Alpha-amylase activity (D.U./g material) was relatively low for 45% patent, midpatent, and clear flours; and relatively high for bran, shorts, and red dog. When α-amylase activity expressed as D.U./g material was calculated as D.U./g wheat, based on yield, activity increased linearly in each mill fraction with increasing wheat α-amylase. When expressed as percent of wheat D.U., bran accounted for 42% of the α-amylase activity and patent flour accounted for 32%; shorts, 9%; clear flour, 8%; midpatent flour, 7%; and red dog, 2%. Sponge cake volume increased from 1280 cc (control) to 1315 cc for the flour milled from wheat containing 0.35 D.U./g. Thereafter, volume decreased rapidly to 908 cc as D.U./g of wheat increased to 4.13. At least 0.2 D.U./g of wheat (about 2.5% sprouted wheat) should be a doubly safe level that would have no adverse effect on sponge cake quality. Sponge cake volume, sprouted wheat (%), amylograph viscosity, falling number, and gas production were all functions of the α-amylase activity of wheat or flour. Different levels of field sprouting should not be assimilated by supplementing unsprouted wheat with a highly sprouted one, and especially not with a highly malted barley.

Introduction

The expression "sprout-damaged wheat" implies that any level of sprouted wheat is undesirable; yet, 0.2 to 0.5% of 100% highly sprouted (malted) wheat is commonly used a flour improver in breadmaking. Some believe that a few tenths of one percent of sprouted wheat significantly and adversely affect cake quality, particularly sponge cake made in Japan. The belief is at least partly based on certain physical and chemical tests that are sensitive to trace amounts of α-amylase produced during the sprouting of wheat. To

U.S. Grain Marketing Research Laboratory, Manhattan, Kansas. Mr. Natsuaki was visiting scientist from Central Research Laboratory, Shikishima Baking Co., Ltd., 6-Nagahei-cho Higashi-ku, Nagoya 461-91, Japan.

verify or clarify the sprouted wheat question, we determined α-amylase activity in field-srouted soft white winter wheats and their mill fractions, and studied its effect on Japanese-type sponge cake, amylograph viscosity, falling number, and gas production.

Materials and Methods

Wheat samples--Seven composites of soft white winter varieties of wheat, from the 1978 crop in eastern Washington, were obtained from the Western Wheat Quality Laboratory (WWQL), USDA, Pullman, WA. The composites contained 0 to 36.2% field-sprouted wheat, 0.03 to 4.13 dextrinizing units (D.U.) of α-amylase activity per g, and typical ash and protein contents (Table 1). Two other soft white winter wheats, 1978 crop, from Centennial Mills, Seattle, WA, contained 0 and 5.5% sprouted wheat and 0.04 and 0.23 D.U. of α-amylase activity per g, respectively. They were used only in studies on the relation of percent sprouted wheat, falling number, amylograph viscosity, and gas production to α-amylase activity. Percent sprouted wheat was determined by the Federal Grain Inspection Service, USDA, Colfax, WA.

Table 1. Ash and protein contents of field-sprouted soft white winter wheats harvested in Washington in 1978 1/.

Wheat composite	Sprouted wheat (%)	α-amylase (D.U./g)	Ash (%)	Protein (%)
Nugaines	0	0.03	1.44	8.7
Nugaines	3.6	0.35	1.36	8.7
Nugaines, Luke, Hyslop	11.0	0.98	1.44	9.6
Soft White Winter	31.5	2.13	1.32	9.0
Soft White Winter	30	2.13	1.46	7.3
Nugaines	30	3.06	1.49	8.1
Soft White Winter	36.2	4.13	1.34	9.6

1/ Chemical data are expressed on a 14% moisture basis.

Experimental milling--Each wheat was tempered to 14.0% moisture for 24 hours, then experimentally milled on six stands of Allis rolls to give five break, one sizing, two tailing, one low grade, and nine middling streams. Mill fractions were 45% patent flour, 10% mid-patent flour, 15% (average) clear flour, bran, shorts, and red dog.

Yield of each fraction was calculated as percent of total products.

Moisture, protein, ash, and α-amylase-- Moisture, protein, and ash contents were determined by AACC approved methods 44-15A, 46-11, and 08-01, respectively. Alpha-amylase activity (D.U./g) was determined by the method of Mathewson and Pomeranz (1979).

Japanese-type sponge cakemaking--Sponge cakes were prepared by the formula and procedure described by Nagao et. al. (1976), except that one batch of cake batter was 2.2 times the amount required for each of two cakes made from each 45% patent flour. Batter for each cake contained 100 g flour (sifted four times); 100 g baker's special-fine sifted sugar; 100 g Fleischmann's* pasteurized frozen whole eggs (FL-28), which contained small amounts of corn syrup, dextrin, and salt; and 28 or 40 g water (including optional flavors). A Hobart mixer Model K5-A was equipped with a 5-qt. bowl; a wire whip for creaming sugar, whole eggs, and water; a flat beater for mixing flour and creamed mixture; and speed settings of 1 to 10 (40 to 240 rpm). Hand mixing of the flour into the creamed mixture was replaced with mechanical mixing in the Hobart (Natsuaki and Finney, 1980) by gently immersing flour in the creamed mixture with a flat beater for 16 sec at setting 1 (40 rpm), then for 3.5-4 sec at setting 10 (240 rpm). The mixer was operated by a GraLab Universal Timer set at 20 sec, so that the setting change was made while the mixer was running. Scaled ingredients (328 to 340 g) were baked at 180°C for 30 min. After a cake was cooled for 1 hr, its volume was determined by rapeseed displacement. Duplicate cakes were made on each of 2 or 3 days. A difference of 38 cc between averages of four determinations was statistically significant at $P = 0.05$.

Gas production, falling number, and amylograph viscosity--Gas production in Gasograph Units (G.U.) of 10 g of 45% patent flour was determined according to the method of Rubenthaler et. al. (1980). The gas production value for control flour was subtracted from each value of the flours milled from field-sprouted wheats. The falling numbers provided by the WWQL had been determined according to AACC approved method 56-81B. Amylograph viscosity of 910 Brabender Units (B.U.) was obtained with a modification of AACC approved method 22-10 on a slurry of 66.5 g of 45% patent control flour and 460 ml distilled water. In determinations of amylograph viscosities, 0.7 g of each 45% patent flour milled from field-sprouted wheat replaced 0.7 g of the control flour. Before flour was added to the amylograph bowl, it was slurried in 300 ml of water in a flask that was rinsed with 160 ml of water. Initial temperature was 25°C.

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* Reference to a company or product does not imply approval or recommendation of the product by the USDA to the exclusion of others that may be suitable.

Results and Discussion

Yield, ash, and protein of mill fractions--Average yields of the mill fractions from the seven wheats (Table 2) were patent flour, 45%; midpatent flour, 10%; clear flour, 15%; bran, 25.8%; shorts, 3.2%; and red dog, 1.0%. Ash and protein contents of the fractions were typical.

Alpha-amylase activity of mill fractions--Alpha-amylase activity was relatively low for 45% patent, midpatent, and clear flours, and was relatively high for bran, shorts, and red dog (Table 2). Alpha-amylase activity in 45% patent flour was about 50% of the wheat activity when it was 1 D.U. or less and about 75% of the wheat activity when it was about 2 D.U. or greater. The α-amylase activity of clear flour was greater than that of 45% patent when the wheat activity was less than or equal to about 1 D.U./g; activity of clear flour was less than that of 45% patent when wheat activity was equal to or greater than about 2 D.U./g.

When the α-amylase activity of each fraction, expressed as D.U./g of the fraction (Table 2), was recalculated as D.U./g wheat (based on the percentage yield), the activity (Figure 1) increased linearly in each mill fraction with increasing wheat α-amylase. When expressed as percent of wheat α-amylase (Figure 2), bran accounted for 42% of the α-amylase activity in the wheat; patent flour accounted for 32% (high because of highest milling yield); shorts, 9% (low because of low yield); clear flour, 8%; midpatent flour, 7%; and red dog, 2% (very low because of lowest yield). For wheat with α-amylase activities less than about 1 D.U./g, bran, shorts, and red dog fractions had higher and 45% patent, 10% midpatent, and clear flours had lower levels of the enzyme than did the corresponding fractions from wheats with α-amylase activities greater than 1 D.U./g.

Related tests vs. wheat α-amylase activity--The determination of sprouted wheat, in the absence of a more suitable test, is a highly subjective method used in trade channels to predict biochemical changes, including the production of α-amylase activity, that take place during the sprouting of wheat. At extreme levels, α-amylase activity can impair the baked products. Wheat α-amylase activity was used as the independent variable in Figure 3A because: 1) α-amylase activity now can be determined quickly, accurately, and objectively; 2) α-amylase activity is a better index of that biochemical change than is percent sprouted wheat; 3) the sprouting of wheat simply is a physical change that accompanies the biochemical changes; and, 4) all related tests, including percent sprouted wheat, can be compared with wheat α-amylase activity as the common denominator.

Percent sprouted wheat increased with increasing wheat D.U. up to about 2 D.U. and then increased disproportionately much less with further increases in wheat D.U. (Figure 3A). Thus, percentages of sprouted wheat equal to 30 or more did not satisfactorily

Table 2.

Yield, α-Amylase Activity, and Ash and Protein Contents of Fractions Milled from Field-Sprouted Soft White Winter Wheats Harvested in Washington in 1978[a/]

Wheat and Fractions	Yield (%)	α-Amylase (D.U./g)	Ash (%)	Protein (%)
0% Sprouted Nugaines	-	0.03	1.44	8.7
Patent Flour	45	-	.33	7.2
Midpatent	10	-	.41	6.3
Clear Flour	17.07	-	.52	8.4
Bran	23.23	-	4.48	11.9
Shorts	3.83	-	2.82	14.1
Red Dog	0.87	-	2.22	12.0
TOTAL	100.00			
3.6% Sprouted Nugaines	-	0.35	1.36	8.7
Patent Flour	45	.18	.32	6.7
Midpatent	10	.15	.37	7.2
Clear Flour	13.98	.21	.48	8.3
Bran	26.94	.69	3.77	12.0
Shorts	2.91	2.08	2.27	14.1
Red Dog	1.15	1.55	1.70	11.7
TOTAL	99.98			

Table 2 (continued)

Wheat and Fractions	Yield (%)	α-Amylase (D.U./g)	Ash (%)	Protein (%)
11% Sprouted NHHW[b/]	-	0.98	1.44	9.6
Patent Flour	45	.48	.31	7.8
Midpatent	10	.65	.38	6.4
Clear Flour	15.45	.61	.49	9.2
Bran	25.44	1.51	4.24	13.4
Shorts	3.16	3.57	2.71	15.4
Red Dog	0.93	2.73	1.91	12.9
TOTAL	99.98			
31.5% Sprouted SWWW[b/]	-	2.13	1.32	9.0
Patent Flour	45	1.57	.32	7.1
Midpatent	10	1.48	.34	6.7
Clear Flour	14.75	1.23	.45	8.7
Bran	26.17	3.49	3.80	12.8
Shorts	3.17	6.26	1.98	14.1
Red Dog	0.90	4.68	1.52	12.4
TOTAL	99.99			
30% Sprouted SWWW	-	2.13	1.46	7.3
Patent Flour	45	1.69	.33	5.2
Midpatent	10	1.08	.36	5.8
Clear Flour	13.97	1.03	.47	6.9
Bran	27.78	3.60	4.05	10.7
Shorts	2.54	6.58	2.33	12.4
Red Dog	0.69	6.84	1.66	10.7
TOTAL	99.98			

Table 2 (concluded).

Wheat and Fractions	Yield (%)	α-Amylase (D.U./g)	Ash (%)	Protein (%)
30% Sprouted Nugaines	-	3.06	1.49	8.1
Patent Flour	45	2.18	.33	6.2
Midpatent	10	2.09	.39	5.4
Clear Flour	15.64	1.45	.48	7.5
Bran	24.95	5.18	4.51	11.9
Shorts	3.34	8.33	2.89	14.3
Red Dog	1.08	6.74	1.62	11.2
TOTAL	100.01			
36.2% Sprouted SWWW	-	4.13	1.34	9.6
Patent Flour	45	3.01	.34	7.7
Midpatent	10	2.87	.37	7.6
Clear Flour	14.21	2.06	.49	9.5
Bran	26.44	6.79	3.80	13.4
Shorts	3.31	9.08	2.04	15.3
Red Dog	1.02	9.43	1.57	13.9
TOTAL	99.98			

a/ Chemical data are expressed on a 14% moisture basis.

b/ NLHW = Nugaines, Luke, Hyslop wheat composite;
SWWW = Soft white winter wheat.

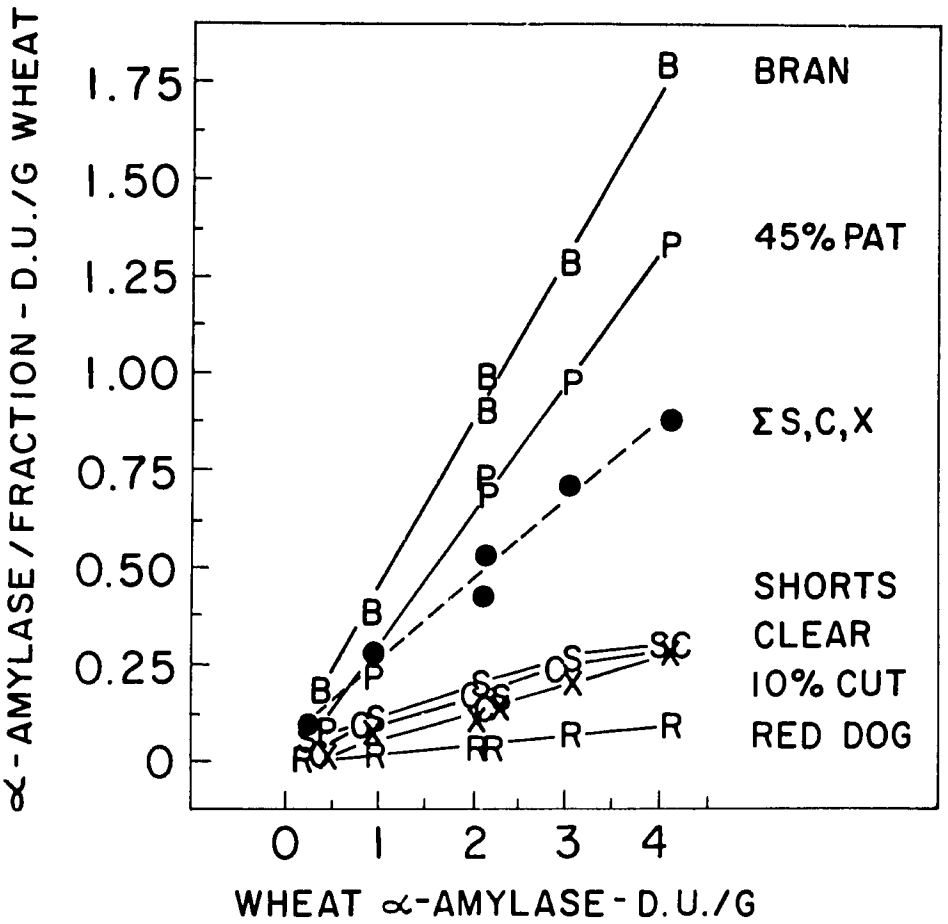

Fig. 1. α-Amylase activities of the mill fractions per gram of field-sprouted wheats *vs* wheat α-amylase activities.

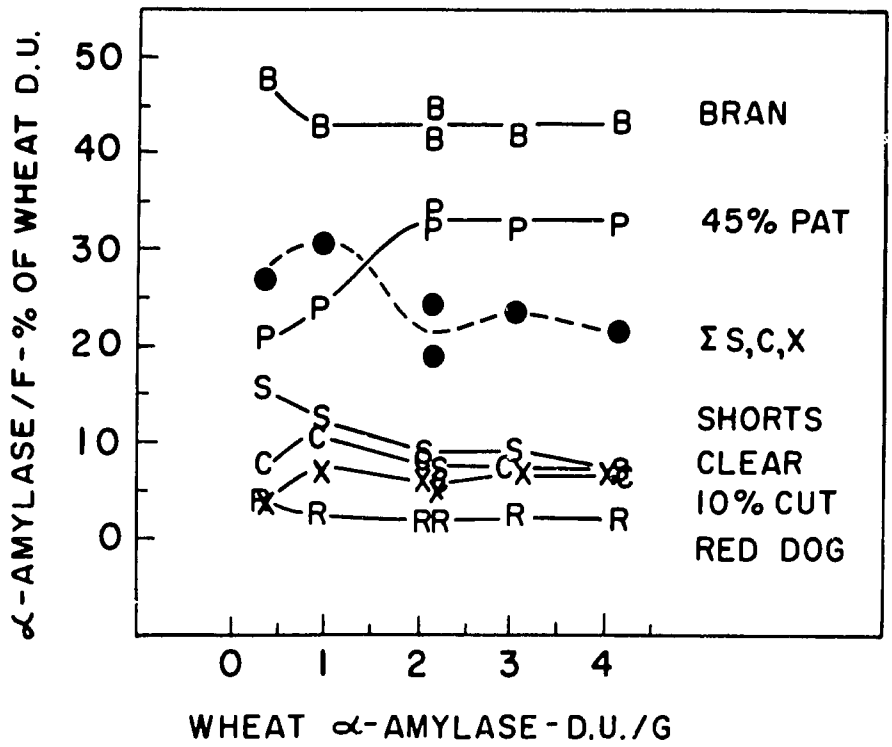

Fig. 2. α-Amylase activities of the mill fractions (F) per gram of field-sprouted wheats divided by wheat α-amylase x 100 *vs* wheat α-amylase activities.

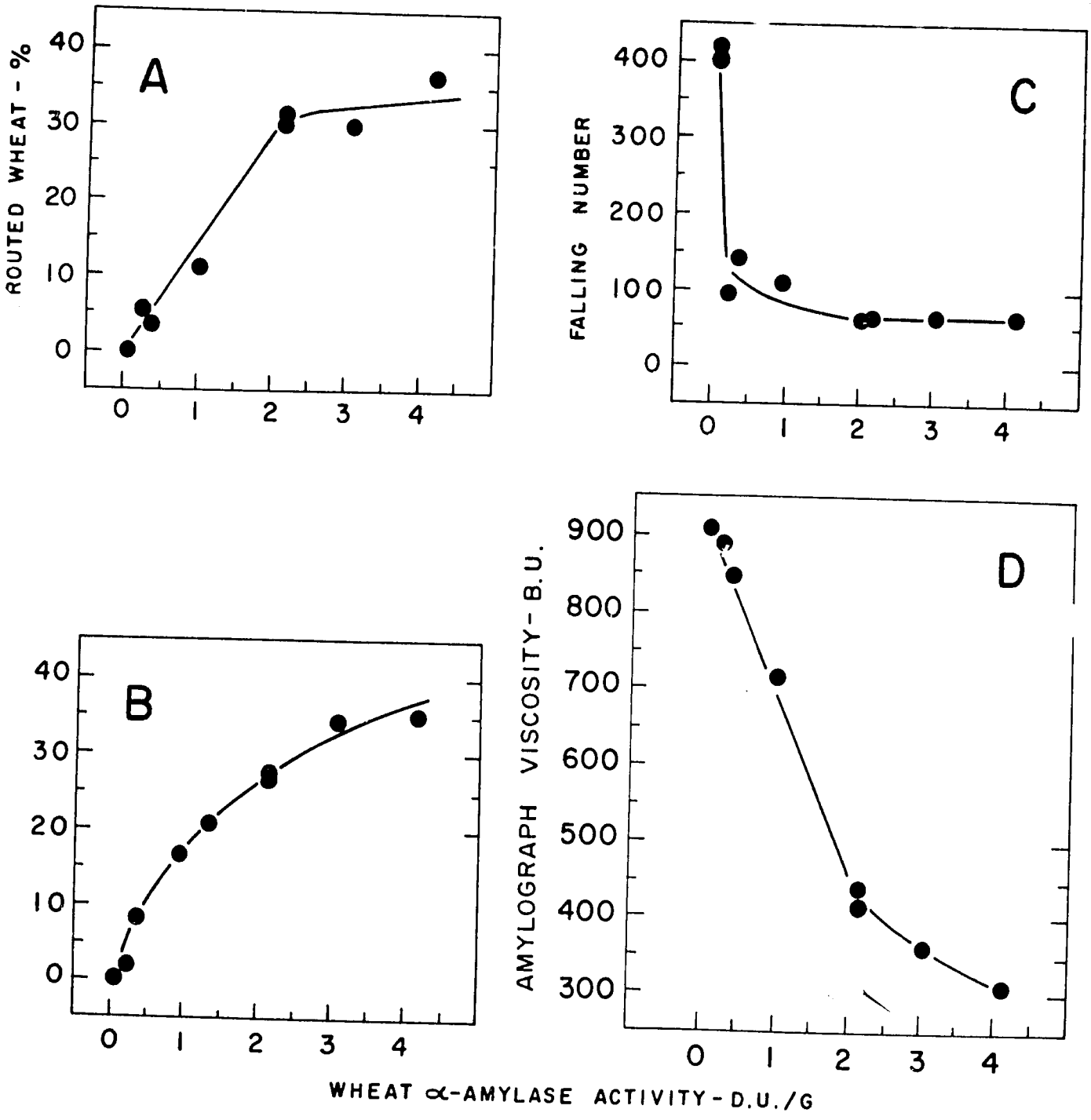

Fig. 3. Percent field-sprouted wheat, falling numbers of field-sprouted wheats, and gas productions and amylograph viscosities of 45% patent flours milled from field-sprouted wheats *vs* wheat α-amylase activities.

reflect wheat α-amylase activities produced during sprouting.

Gas production was a consistent function of wheat α-amylase activity, although rate of change of gas production per 1 D.U. decreased with increasing wheat D.U. (Figure 3B).

Falling number decreased from 400 (control) to 140 for the wheat containing only 0.35 D.U./g of α-amylase activity, approached 100 at 1 D.U./g, and reached a minimum of about 65 at 2 D.U./g (Figure 3C). Falling number affords little differentiation between wheats that have α-amylase activities of about 0.5 to more than 4 D.U./g.

Amylograph viscosity was decreased significantly by trace amounts of α-amylase. For example, the wheat that contained 0.35 D.U./g yielded a 45% patent flour that contained 0.18 D.U./g (Table 2, 3.6% sprouted); then there was only 0.7 g flour X 0.18 = 0.126 D.U./66.5 g total flour or 0.0019 D.U./g for amylograph viscosity (850 B.U.) that was 60 B.U. less than the control (910 B.U.).

Sponge cake volume vs. wheat α-amylase activity--The volume of Japanese-type sponge cakes made with 40% water increased from 1280 cc for the control to 1315 cc for the 45% patent flour milled from wheat containing 0.35 D.U./g (Figure 4). Crumb grains and other cake properties were normal (Figure 5, top and 2nd row). Thereafter, volume decreased rapidly to 908 cc at 4.13 D.U./g of wheat (Figures 4-6). Thus, an α-amylase activity of at least 0.2 D.U./g of wheat (about 2.5% sprouted wheat) should be a doubly safe level that would have no adverse effect on sponge cake quality.

Sponge cakes made with the reduced absorption of 28% (Figures 4-6) demonstrated that it is possible, although probably not economical, to greatly reduce the adverse effects of α-amylase in Japanese-type sponge cakes.

Sponge cake volume vs. related tests--The relations between cake volume and percent sprouted wheat (Figure 7A) and between cake volume and gas production of flours from field-sprouted wheats (Figure 7B) were similar to the relation between cake volume and α-amylase activity in wheat (Figure 4).

Wheat with a falling number of 140 yielded a sponge cake flour equal to the control (Figure 7C). As falling number decreased below 140, cake volume decreased sharply.

An amylograph viscosity of at least 100 B.U. less than that of the control flour (910 B.U.) is associated with normal quality in cakes made with 40% water (Figure 7D).

Amylograph viscosity, falling number, sprouted wheat, and gas production are indexes of sponge cake volume and all are functions of the α-amylase activity of wheat or flour.

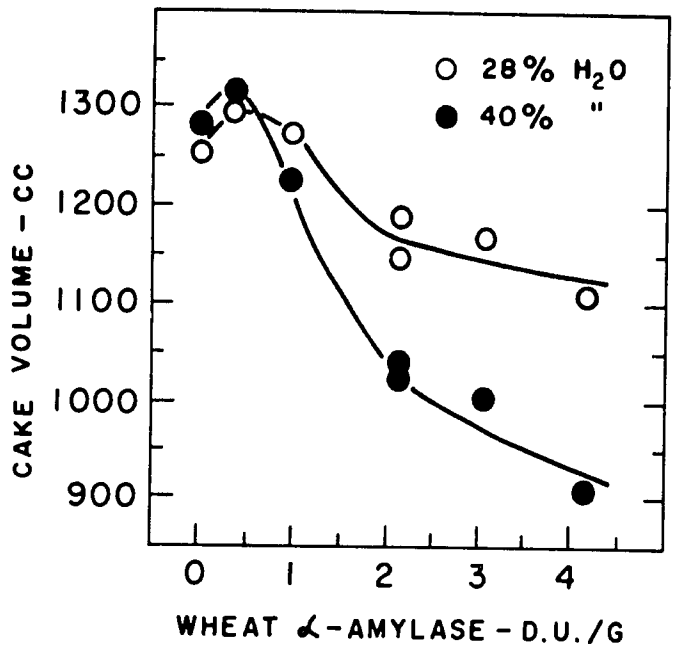

Fig. 4. Changes in volume of Japanese-type sponge cakes (28% and 40% water absorptions) baked from 45% patent flours milled from field-sprouted wheats that varied greatly in α-amylase activities.

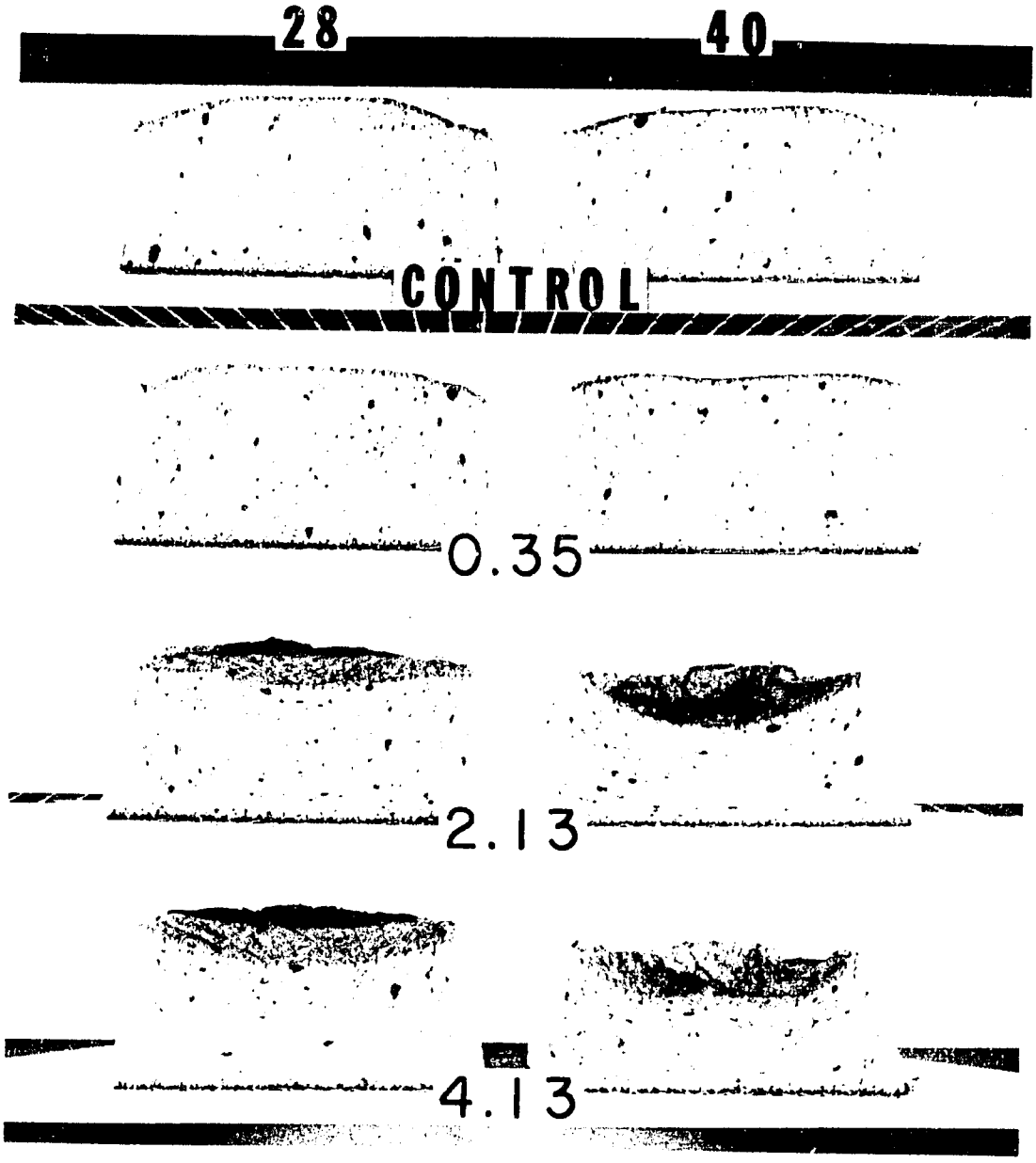

Fig. 5. Japanese-type sponge cakes (28% and 40% water absorptions) baked from 45% patent flours milled from field-sprouted wheats that contained 0 to 4.13 D.U. of α-amylase activity per g.

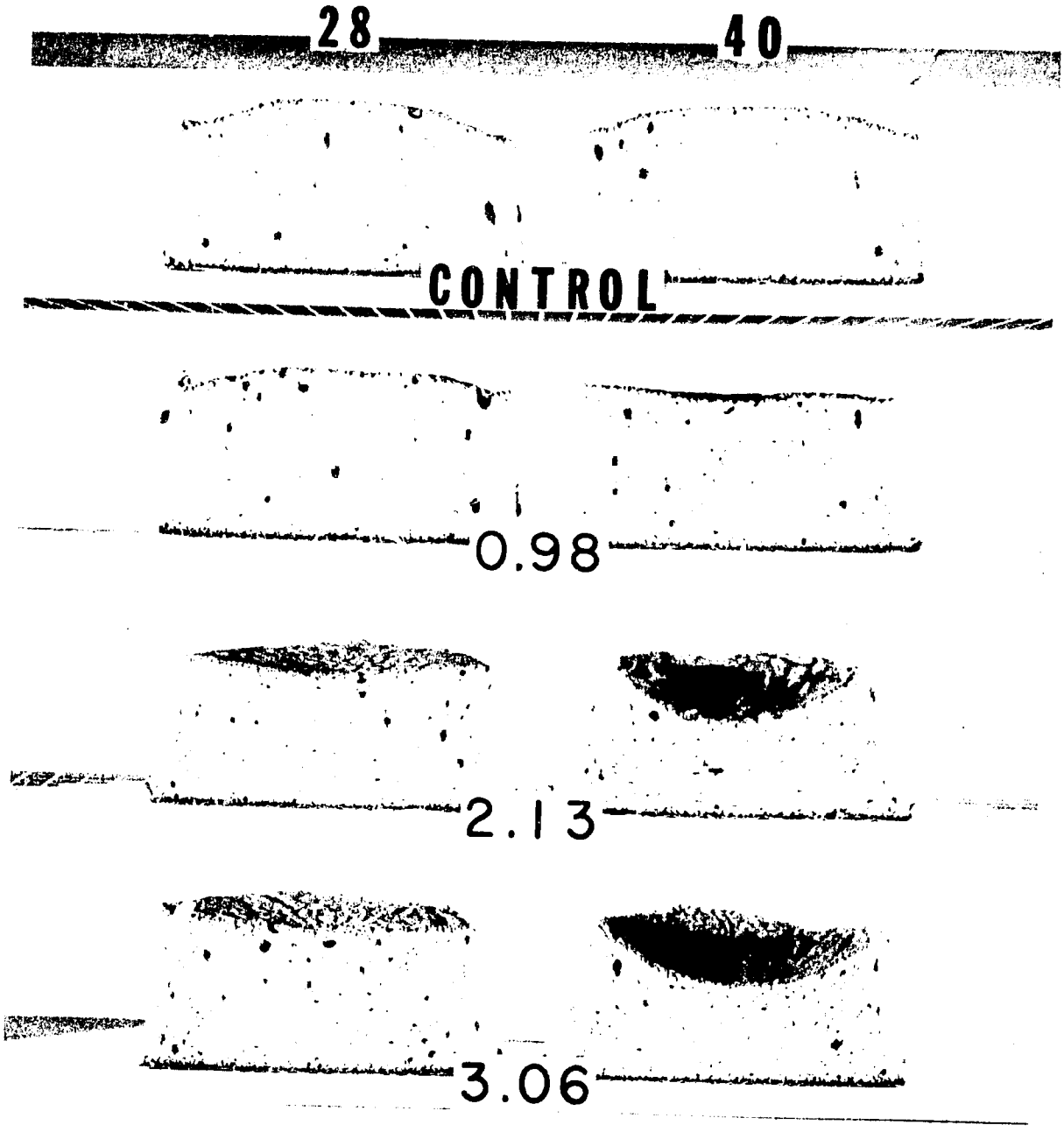

Fig. 6. Japanese-type sponge cakes (28% and 40% water absorptions) baked from 45% patent flours milled from field-sprouted wheats that contained 0 to 3.06 D.U. of α-amylase activity per g.

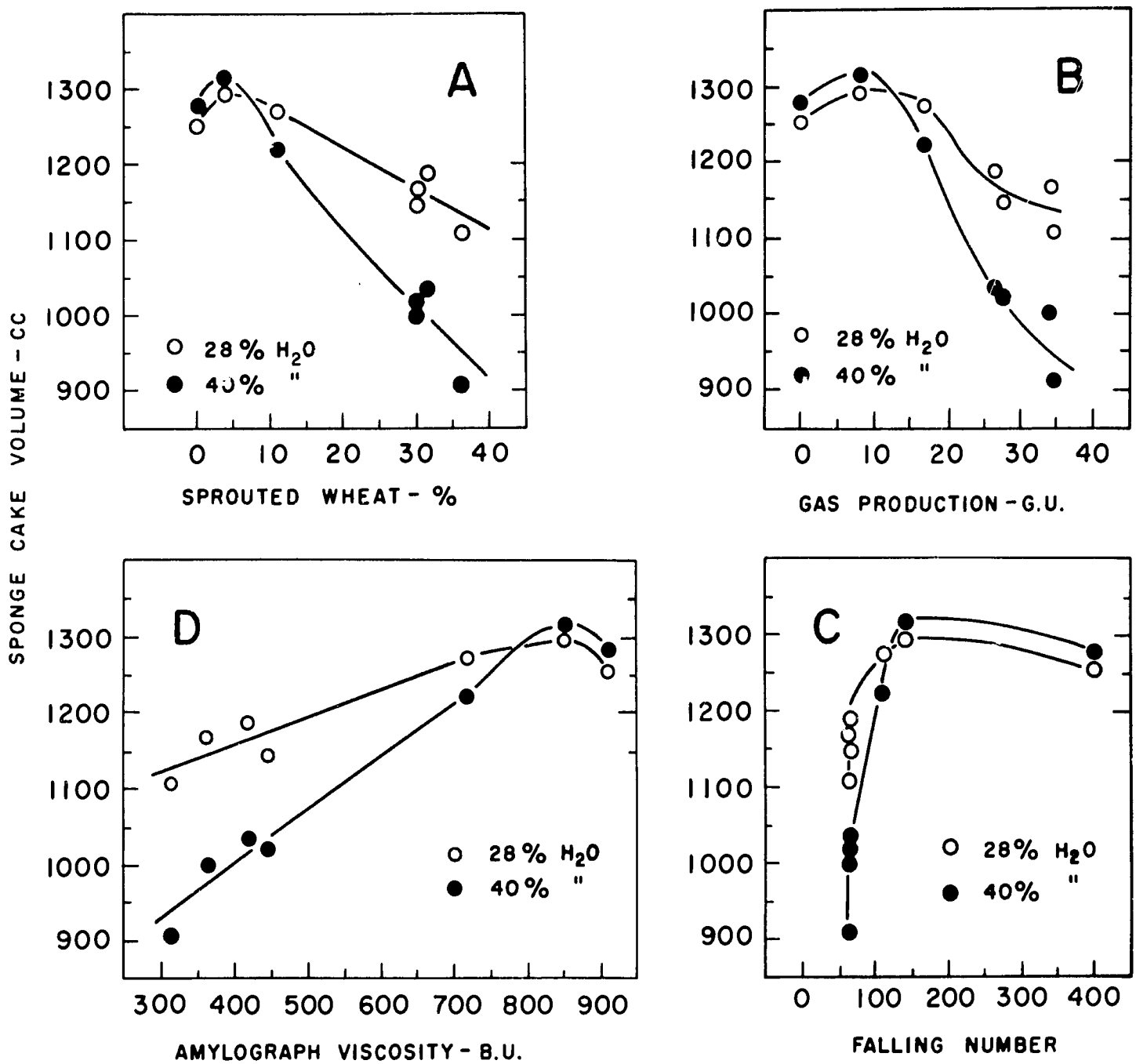

Fig. 7. Volumes of Japanese-type sponge cakes (28% and 40% water absorptions) baked from 45% patent flours milled from field-sprouted wheats *vs* amylograph viscosities and gas productions of the flours, falling numbers of the wheats, and percent sprouted wheat.

Adverse effects of α-amylase supplements--When a non-sprouted control 45% patent flour was supplemented with barley malt of very high α-amylase activity (52 D.U./g), its sponge cakemaking potential (Figure 8, left) was more adversely affected than that of the same control flour supplemented to the same level of enzyme activity with a flour (2.12 D.U./g) milled from a field-sprouted wheat that contained only 3 D.U./g (Figure 8, right). Cake made from patent flour that contained 0.48 D.U./g and was milled from a field-sprouted wheat containing 0.98 D.U./g (Table 2, 11% sprouted) was less adversely affected (Figure 6, 2nd row, right) than was cake made from the control flour supplemented to 0.43 D.U./g with the flour from field-sprouted wheat containing 3 D.U./g (Figure 8, bottom right). A similar but less striking comparison can be made between sponge cakes baked from flours containing 0.17 D.U./g (Figure 8) and cake baked from the flour (0.18 D.U./g) milled from field-sprouted wheat containing 0.35 D.U./g (Figure 5, 2nd row, right). Thus, different levels of field sprouting should not be assimilated by supplementing unsprouted wheat with a highly sprouted one, and especially not with a highly malted barley.

Biochemical changes that occur in lightly sprouted grain differ quantitatively and probably qualitatively from those that occur in highly sprouted grain. For instance, the ratio of amylolytic to proteolytic enzymes may change as the grain is sprouted to increasingly advanced levels. Even the formation of new or disappearance of old compounds, including enzymic activities, might occur in highly sprouted grain. Consequently, it would be presumptuous to assume that adding equal amounts of α-amylase from a lightly or highly sprouted grain will have the same overall effects on functional properties, including performance of batters in cakemaking.

Literature Cited

American Association of Cereal Chemists. Approved methods of the AACC. Method 08-01, approved October 1976; Method 22-10, approved May 1960; Method 44-15A, approved April 1967; Method 46-11, approved October 1976; Method 56-81B, approved November 1972. The Association: St. Paul, MN.

Mathewson, P. R. and Y. Pomeranz. 1979. Modified chromogenic α-amylase assay for sprouted wheat. J. Assoc. Off. Anal. Chem. 62(1): 198.

Nagao, S., S. Imai, T. Sata, Y. Kaneko, and H. Otsubo. 1976. Quality characteristics of soft wheats and their use in Japan. I. Methods of assessing wheat suitability for Japanese products. Cereal Chem. 53(6):988.

Natsuaki, O. and K. F. Finney. 1980. A modified sponge cake test-baking method that employs mechanical mixing of the batter. Being prepared for publication in Cereal Chem.

Rubenthaler, G. L., P. L. Finney, D. E. Demaray, and K. F. Finney. Gasograph: Design, construction, and reproducibility of a sensitive 12-channel gas recording instrument. Cereal. Chem. (in press).

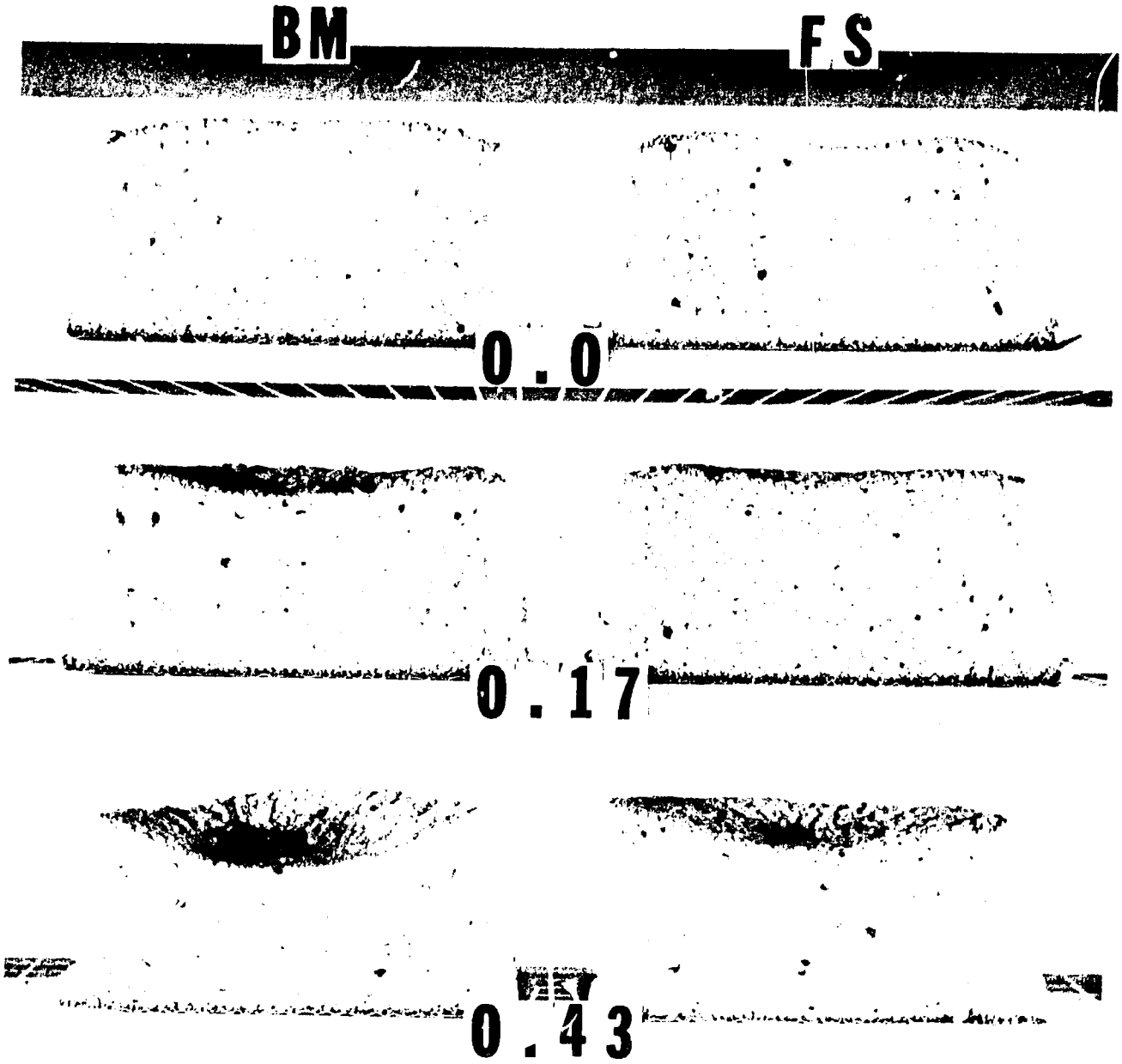

Fig. 8. Japanese-type sponge cakes (36% water absorption) baked from 45% patent flour that contained 0, 0.17, and 0.43 D.U./g supplements of barley malt (BM, 52 D.U./g) and flour (2.12 D.U./g) from field-sprouted (FS) wheat (3 D.U./g).

PROTEIN CONTENT OF WHEAT -- CROP PHYSIOLOGICAL AND BREEDING ASPECTS

Th. Kramer
The Netherlands

Abstract

Within cultivars correlations between grain yield (GY) and grain protein content (GPC, %) may be positive, zero or negative, depending on the fertility of the soil and the nitrogen dressing applied.

Between cultivars GY as a rule is negatively related with GPC. An interpretation of this inverse relationship is expected to be found in genetical, energetical and crop-physiological aspects. The crop-physiological interpretation appears to be of major significance.

Advances in GY are accompanied by a corresponding drop in straw yield (= an increase of the harvest-index (HI)). The vegetative biomass constitutes the major reservoir for grain protein during grain filling. Thus, this breeding methodology drastically deprives the grains of their protein source.

By manipulating the HI within cultivars the strong negative relationship between HI and GPC could be demonstrated. It indicates that gross between cultivar variation in GPC is based on a) HI differences, and b) net genetic variation. Experiments have shown that net genetical effects on GPC are relatively unimportant.

A high GPC, high HI cultivar can only be realized in combination with extreme earliness, and, therefore, with a low total biomass and low grain yield level.

Introduction

The protein content of wheat is variable, both within and between wheat cultivars. This variation in protein content is mostly associated with variation in grain yield. This is not unexpected since the protein content is expressed as a percentage of the grain yield.

Within cultivars the correlation between grain yield (GY) and grain protein content (GPC, %) may be positive, negligible or negative. This depends on the fertility level of the soil and was explained by Kramer (1979). Relations between N-dressing, N-uptake, grain yield and GPC are summarized in Figure 1. The range over which the GPC can vary is cultivar dependent.

Between cultivars the correlation between GY and GPC is almost always negative. It varies generally between -0.40 and -0.85 tending

Department of Plant Breeding, Wageningen Agricultural University

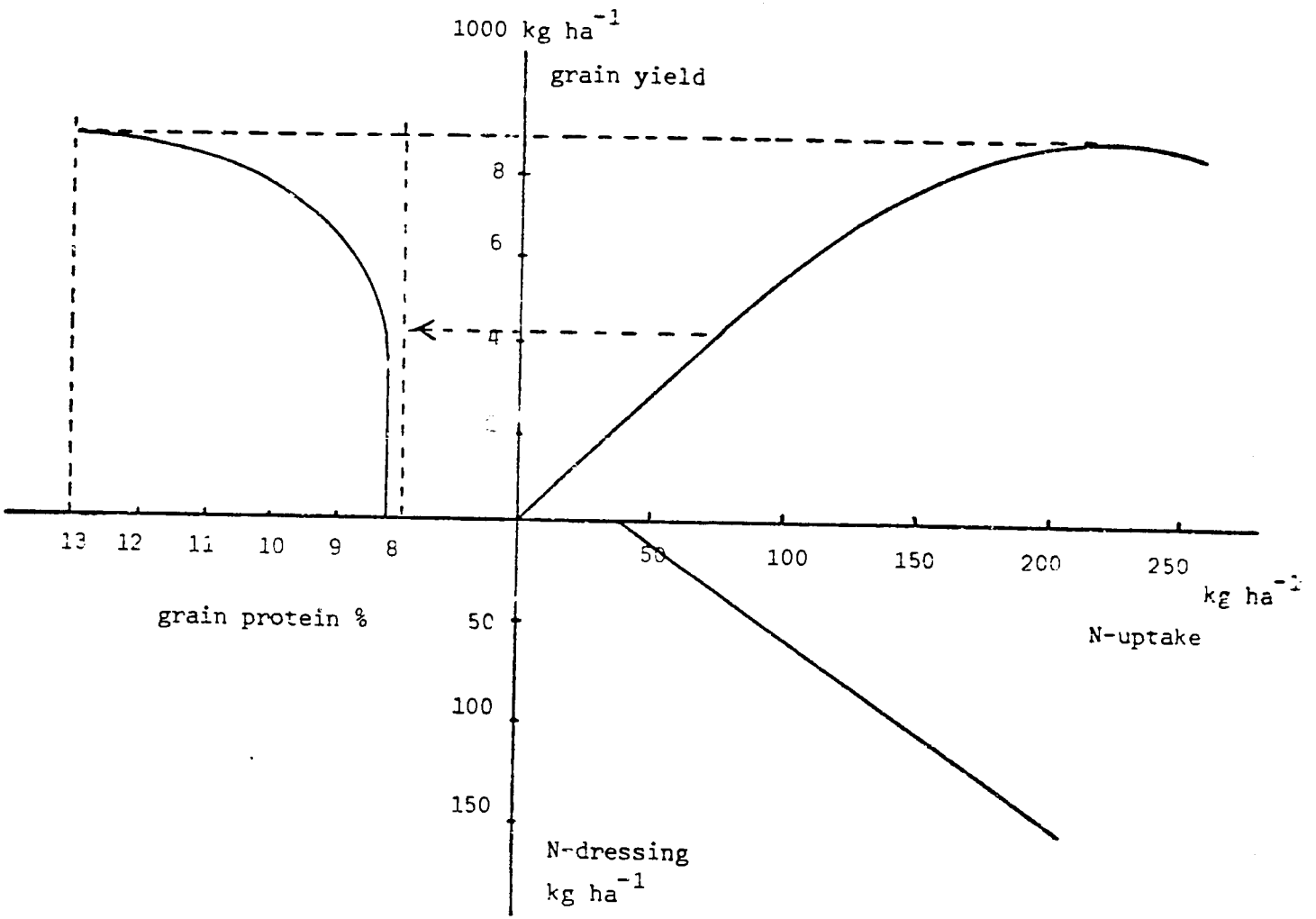

Figure 1. Relation between N-dressing, N-uptake, grain yield and grain protein content.

to be lower as more cultivars or lines are involved in the comparison. Several interpretations for the negative relationship between GY and GPC can be given and are briefly mentioned here.

A genetic analysis hypothesizes linkage between + genes for GY and - genes for GPC. This linkage diminishes the likelihood of recombination of + genes for GY with + genes for GPC. However, in principle, recombination is possible. It is, therefore, realistic to expect a certain frequency of favorable recombinants. Only in the extreme situation of pleiotropy is no recombination to be expected.

The criticism to this genetic point of view is that all genes which effect GY inevitably must also influence the GPC, because the GPC is expressed as a percentage of GY. Logical reasoning leads one to the conclusion that any gene affecting the GY must be pleiotropic in the genetic sense. Any genetic gain for GY is a genetic loss for GPC. A genetic gain for GPC cannot be distinguished from a genetic loss for grain yield.

A negative correlation between GY and GPC is also expected on the basis of energetical considerations. The production of proteins is biologically expensive. Moreover, energy has to be spent for their maintenance. Bhatia & Rabson (1976) calculated on the basis of results obtained by Penning de Vries (1975) that an increase of 1% in protein content -- in the absence of a yield loss -- is to be expected when the photosynthetic production could be increased by 1%. At unchanged photosynthetic production and for a harvest-index (HI) of 0.50, a 1% increase in GPC would necessitate a 2% decline in GY.

The predictive value of the theoretical calculations is poor. Experimental evidence indicates that an increase of 1% in GPC occurs at the cost of 7.5% GY loss (Figure 2). Energetic theory thus only explains part of reality. The crop-physiological point of view provides the best insight in the GY-GPC problem. Improvement of wheat yields has been realized largely by changing the dry matter distribution between grain and straw. To my knowledge no systematic trend of old versus new cultivars in the efficiency of light utilization has been demonstrated.

The advance in GY has been accompanied by a more or less equivalent drop in straw yield (Austin et al. 1978, p. 161). Since, as a rule, 60-80% of the grain proteins are already present (although in a different form) in the straw at anthesis, reduction of straw biomass will partially deprive the grains of their major protein reservoir.

Problem

When comparing cultivars with respect to GPC the harvest index effect should be taken into account. However, to improve the protein content of present cultivars, breeders generally start a crossing program with genotypes having an extremely high protein content. Little attention is paid to HI plant type or growth rhythm of these

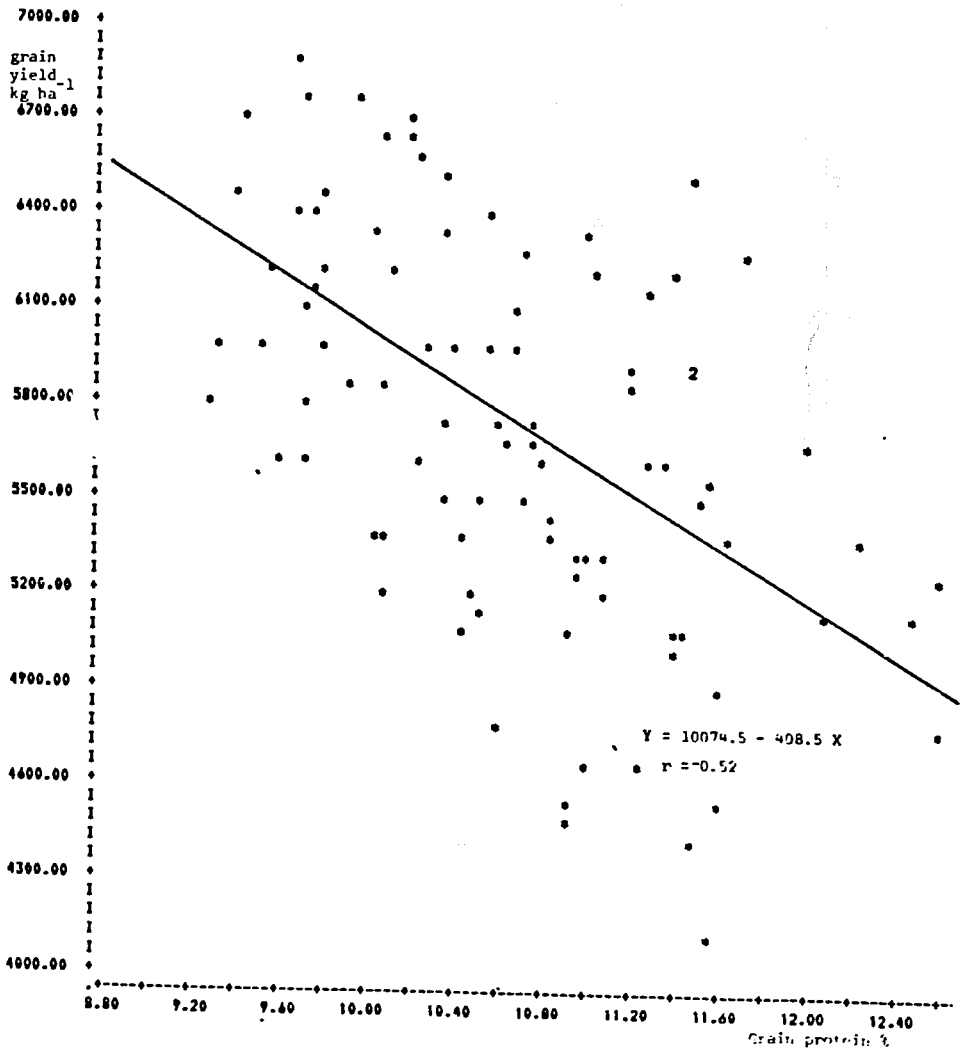

Figure 2. Relation between grain yield and grain protein content in 98 spring wheat lines.

crossing parents. But when the superiority of the crossing parents is largely a result of their low HI, no selection progress should be expected, for selection for GY in later generations will lead to an increased HI and as a result lower the GPC. The crossing program only makes the introduction of deleterious alleles for GY likely. Knowledge of the HI effect on the GPC would allow the GPC to be adjusted for HI. The assumption to be satisfied is that HI effect on GPC is cultivar independent.

This paper will provide some results of an experiment designed to quantify the HI effect on GPC and to test the above assumption. Ten different cultivars/advanced breeding lines differing in grain yield, protein content and harvest-index were used. Within cultivar variation for HI was brought about by straw removal and various nitrogen applications. Details of these treatments can be found in Table 1.

Table 1. Description of the cultural practice corresponding with treatments 1 to 5, the mean harvest index and protein content of the 10 varieties.

Treatment	Cultural practice	Harvest index (%)	Grain protein content (%)
1	Straw removal in F_4	41.4	10.7
2	Control	40.7	10.4
3	40 kg N ha^{-1} in F_4	37.8	10.8
4	80 kg N ha^{-1} in F_4	37.8	12.1
5	120 kg N ha^{-1} in F_4	35.1	13.4

Results

The 5 different cultural practices lead to the expected variation in HI and GPC (Table 1). The correlation between the two variables was -0.87 and the regression equation of GPC on HI was as follows: GPC = 28.12 - 0.43 HI, averaged over the 10 cultivars. Thus for each unit (= %) increase in HI the decline in GPC is 0.43.

When the protein content was regressed on the HI for each variety separately, the regression coefficients varied between -0.16 and -0.46 (Table 2). For 7 out of the 10 varieties the b's were significant. The average values of r and b were -0.64 and -0.291. Both values are slightly lower than those extracted from published reports (Kramer, 1979). Although significant treatment x variety interaction was present for HI, indicating heterogeneity in the response of HI to the cultural treatment, the mean square (MS) for interaction effects was only about 5% of the variety MS. This indicates that the variety specific change of the HI is relatively unimportant with respect to the variety differences in HI. The rule of thumb of uniform change in HI therefore will not lead to serious errors.

Table 2. Relation between harvest index and grain protein content within 10 cultivars.

Cultivar	Correlation coefficient r	Regression coefficient I, GPC
Lincoln	-0.38	-0.300
SVP-1	-0.47	-0.169
Arminda	-0.57	-0.157
SVP-2*	-0.59	-0.268
Y 10738	-0.60	-0.275
Y11184	-0.65	-0.268
Marksman	-0.70	-0.298
Y 10982	-0.78	-0.330
Y 77	-0.78	-0.461
Lancota	-0.84	-0.388
Mean	-0.64	-0.291

*For cultivars below the dotted line r and b are significant, $P<0.05$.

The between-cultivar variation in GPC, which could be removed by adjustment for the overall effect of HI on GPC, was negligible (Table 3). This was not expected, but reveals an important aspect. The cultivars that were used in the experiment belonged to two clearly different maturity groups. Cultivars from the Nebraska program were about two weeks earlier, both in heading and maturity. In comparison with the N. W. European cultivars the difference in biomass was therefore large. Under these conditions the assumption of equality in biomass is violated and the GPC-HI relation is disturbed. However, an important additional phenomenon is revealed: earliness tends to promote a higher GPC.

This could also be demonstrated for a number of breeding lines in spring wheat (Figure 3). The higher GPC of spring wheat in relation to winter wheat may also relate to this phenomenon. The effect of duration of different growth phases and the whole growing period on GPC should be studied in more detail. As can be seen from Table 3, after covariance analysis of GPC with HI, about 50% of the treatment MS still remains. Apparently, the nitrogen treatments have also had -- apart from an indirect effect through HI -- a direct effect on GPC. Realization of within-cultivar variation with different cultural practices (e.g. water regimes) may be preferable, but are practically a problem under N. W. European climatic conditions.

In Figure 4 several environmental and genetic factors influencing the GPC are illustrated. In future research on GPC more emphasis should be put on 1) the possibility of increasing the biomass production within the limits of a certain growth vegetation period; 2) variation in protein content of the vegetative biomass before the onset of protein translocation and 3) translocation efficiency; and 4) activity of the root system in taking up nitrogen during the reproductive phase.

Table 3. Analysis of variance and covariance for harvest-index (HI) and grain protein content with harvest-index.

Source of variation	Harvest index		Grain protein content			
	df	MS	df	MS	df	MS
Covariates (HI)	-	-	-	-	1	57.419**
Main effects	14		14		14	
Replication	1	5.269	1	0.069	1	0.056
Treatment	4	129.442**	4	31.464**	4	16.364**
Cultivar	9	92.885**	9	9.966**	9	9.231**
2-way interaction	49	4.890*	49	0.333	49	0.335
Error	36	2.393	36	0.309	35	0.314

* P<0.05
** P<0.01

Literature Cited

Austin, R. B. et al. 1978. Yields of old and modern winter wheat varieties. In: Ann. Rep. Plant Breeding Inst., Cambridge, pp. 160-163.

Bhatia, C. R. and R. Rabson. 1976. Bio-energetic considerations in cereal breeding for protein improvement. Science 194:1418-1421.

Kramer, Th. 1979. Environmental and genetic variation for protein content in winter wheat (*Triticum aestivum* L.). Euphytica 28: 209-218.

Penning De Vries, F. W. T. 1975. Use of assimilates in higher plants. In: Photosynthesis and productivity in different environments (J. P. Cooper, ed.), Cambridge Univ. Press, pp. 459-499.

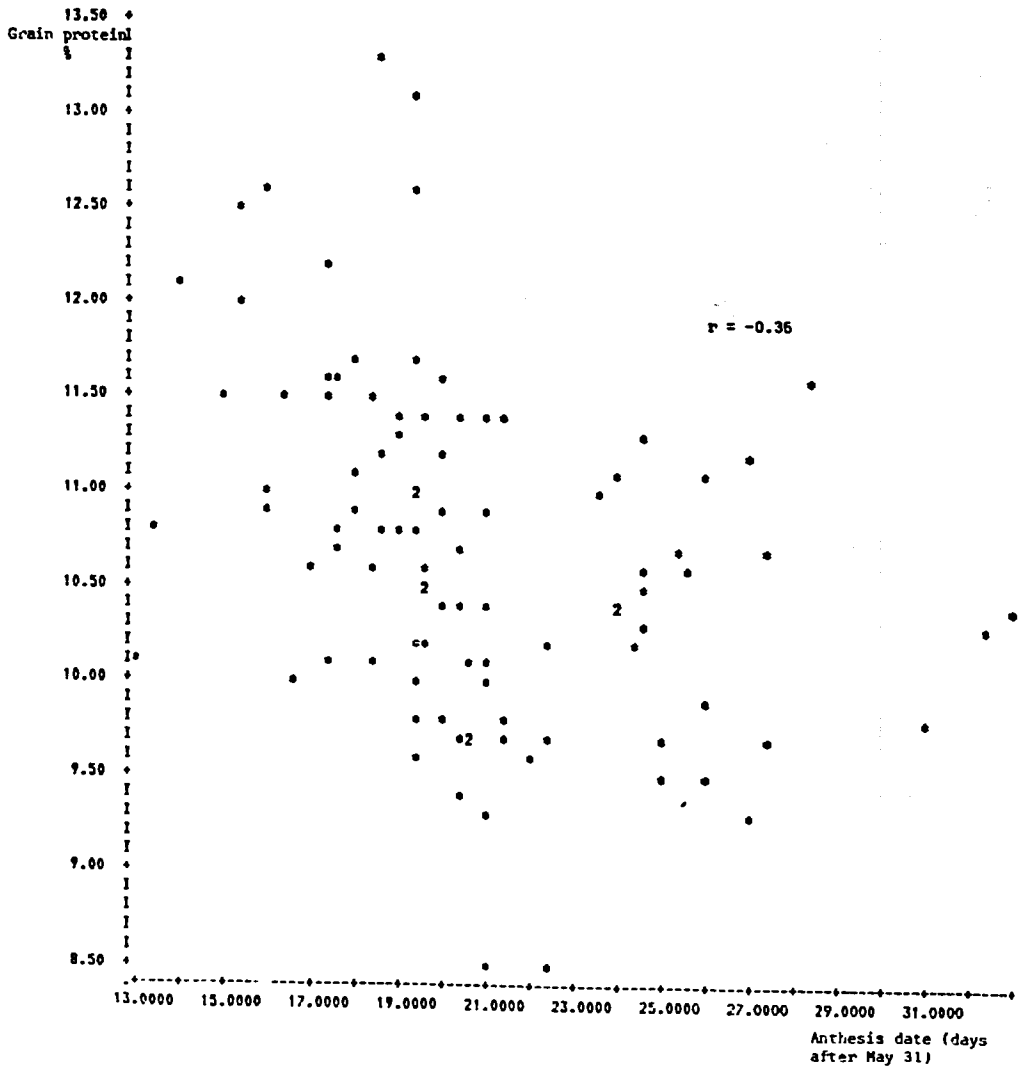

Figure 3. Relation between date of anthesis and grain protein content in 98 spring wheat breeding lines.

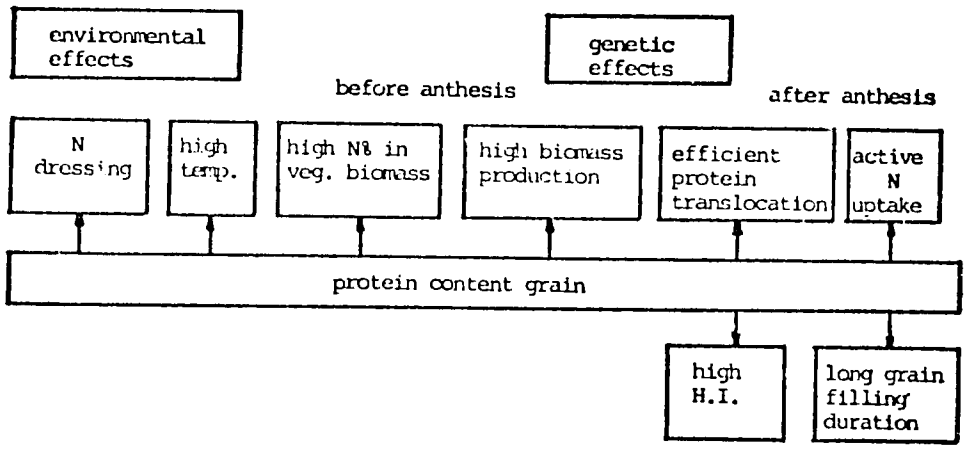

Figure 4. Diagrammatic representation of environmental and genetic effects on grain protein content.

RESULTS OF A FIRST SELECTION CYCLE TO IMPROVE CRUDE PROTEIN CONTENT IN BREAD WHEAT

M. Rousset, M. Pichon and G. Branlard
France

Summary

The main aim of wheat breeding for animal feeding value is the increase of crude protein content of grain. For this purpose, our laboratory began in the late sixties a breeding program for improvement of crude protein content of wheat grain while maintaining a high productivity level.

During a first period we collected and studied genitors, and in a second period we made hybridizations between the best of these. Early in the seventies, selection work was undertaken at Clermont-Ferrand, in central France, an environment where high protein content and high grain yield are favoured.

After one selection cycle for grain yield and protein content the best lines showed a 10 to 45% increase in protein yield compared to check varieties depending on genotype and year.

The progress observed in the Clermont-Ferrand environment can be explained as follows: increase of crude protein content of grain combined with higher or equal grain yield. For example, taking into account the high grain yield, the genetical progress for bred lines is about 1 to 2 protein points compared with check varieties of best agronomical value such as Clement in the Clermont-Ferrand environment.

Multilocation yield trials conducted in 1977-78 in the northern half of France seem to minimize progress noted at Clermont-Ferrand. The following hypothesis is possible. In growing nurseries and trials in only one location there could be preferential selection of genotypes due to a favorable genotype - environment interaction and resulting in high level protein and yield character expression.

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Considerable quantities of bread wheat are used for animal feeding in France. As shown in Table 1, self-consumption on farms and commercialized animal feed totaled about 4.94 and 4.26 millions of metric tons in 1978-79 and 1979-80, respectively. In view of this situation, it seemed that an improvement, even limited, of grain crude protein content could contribute to a reduction in the expensive complementation of animal rations by high protein content feeds (especially seed-cake).

Institut National de la Recherche Agronomique, Clermont-Ferrand.

Table 1. Some data on bread wheat production and commercialization in France during the last two years (1978 and 1979 harvest).

		Harvest year	
		1978	1979
	Area (x 1000 ha)	4081	3935
	Average yield (q/ha)	51	48
millions of metric tons	Production (1)	20.81	18.71
	Self consumption (2)	3.64	2.71
	Collect (3) = (1) - (2)	17.17	16.00
	French consumption	6.42	6.55
	- industrial utilization	4.64	4.47
	- animal feed	1.30	1.55
	- diverse utilizations	0.48	0.53

from P. d'assignies (1979) (Association Generale des Producteurs de Ble)

The conditions in which plants are grown can greatly modify expression of genotypic value for yield and protein content; the magnitudes of resulting variation are generally wider than those due to genetic variability between genotypes well adapted to French climatic conditions.

Therefore, varietal selection must act at two levels:

1) on the ability of a genotype to store proteins in its grain (best protidosynthesis?);

2) on genotype reaction to the application of different growing conditions (location, year, cultivation techniques) resulting in given yield and protein content.

Wheat crude protein content is a character with multigenic heredity considerably influenced by environmental conditions. Another point is the difficulty encountered by breeders who want to improve grain crude protein content while maintaining high grain yield because of the negative correlation between grain yield and protein content.

According to V. A. Johnson (1978) from Nebraska University there is notable genetical variability for grain protein content of bread wheat grain. The varieties Atlas 66 and Atlas 50 obtained from the Brazilian variety Frondoso have been the genetic sources of high protein content most widely used in breeding programmes. The variety Lancota, commercialized since 1975 in the U.S.A., possesses a yield potential equivalent to that of the best varieties grown in the United States southern plains with a protein content 1 to 2 points higher. For this author further progress is still possible to improve grain protein content with yield equivalent to that of Lancota.

For the last 10 years, our laboratory has been engaged in a programme of grain crude protein content improvement. In addition to this search for quantitative protein improvement, we have prospected in diversified wheat material to try to find genitors with increased lysine content in the protein to improve protein quality. We failed to find any significant variability for this character.

Material and Methods

Prospection and genitor studies -- In our laboratory, numerous potential genitors have been gathered and studied as a "quality collection" grown for several years in a nursery. The main physiological and agronomical plant characters and the grain utilization value (protein content, baking quality...) are observed.

Some special genotypes were studied in 1970-71 microplot trials. Besides all the characters observed in these trials, a joint study of yield and protein content was made.

Selection for grain protein content increase -- Some genitors of the quality collection were chosen and crossed to obtain, after selection, lines of good agronomical value, particularly with short stature, high productivity, good resistance to the main diseases and increased grain protein content. The best cross, revealed a posteriori, was the following: Mexico 51 - Courtot x Pembina - Courtot. Genitor pedigrees are given in Table 2. Selection was made in nurseries and microplot trials grown in only one location (Clermont-Ferrand) according to the pedigree method scheme. Selected characters depending on generations are given in Table 3. A multilocation trial was conducted in 1977-78 in northern France on only one line coming from the cross (1) in comparison with check lines to assess agronomical and technological characteristics of this material in diversified growing conditions.

Analytical methods -- Protein content analysis was made with a NEOTEC Grain Quality Analyzer (infrared reflectance). Prolamin studies were conducted with polyacrylamide gel electrophoresis following the method described in the Table 4. Genetic diversity between genotypes evaluated from prolamin electrophoregrams is given by a dissimilarity index measured between parents and selected lines compared two by two. Calculation principles of this index are given in scheme 1.

Results

The characteristics of original genitors -- Experimentation conducted in 1970-71 with some genitors from the "quality collection", the yield and protein content of which are summarized into graph 1, confirms the well known negative correlation between grain yield and crude protein content, with a correlation coefficient $r = -0.704$ (highly significant) and regression line equation $y = -0.146\,x + 22.8$. Parents of the crosses studied are marked by arrows. Pembina and Mexico 51 are of high protein content but have poor yields whereas "Courtot" combines high yield with relatively lower protein content.

Table 2. Parental line pedigrees.

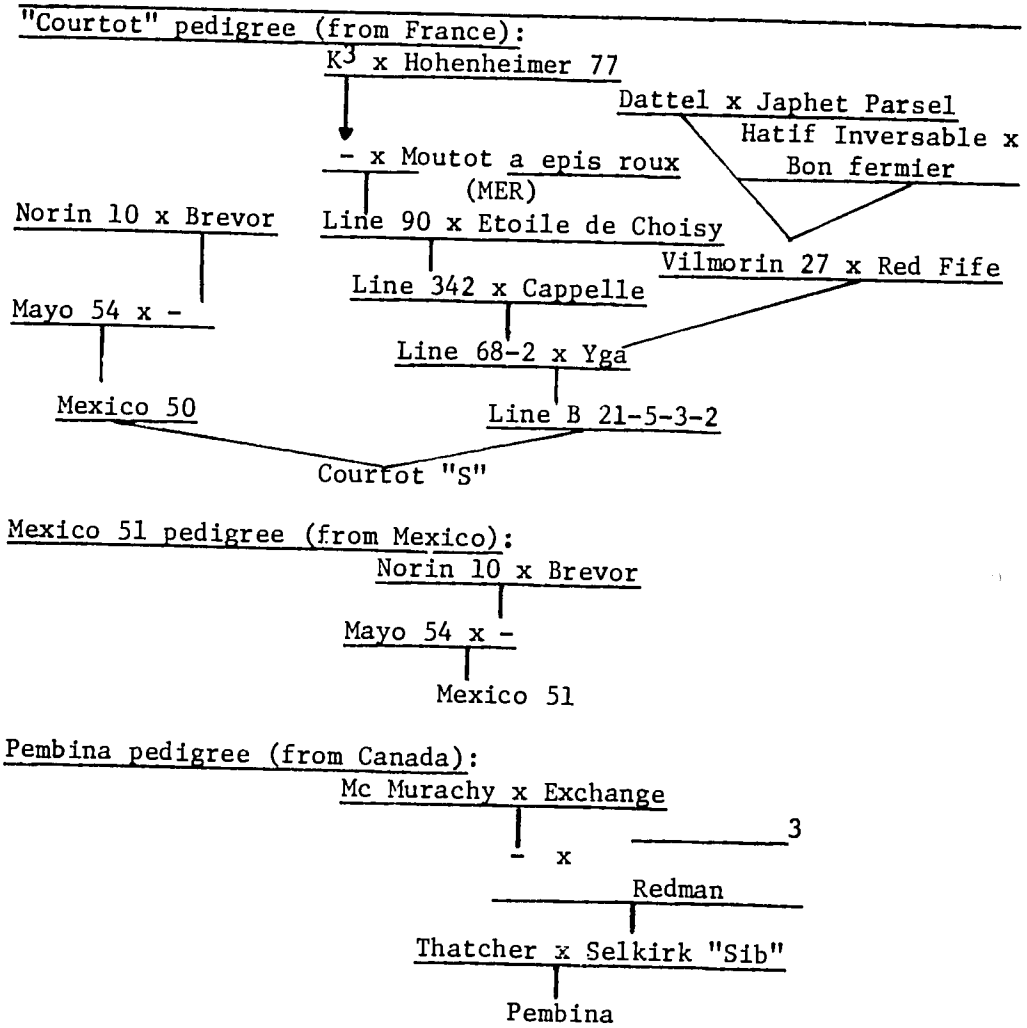


Table 3. Main selected characters depending on generations.

Generation	Nurseries	Microplot trials
F2 ⟶ F4	-disease resistance (rusts, powdery mildew) -short stature -heading date -grain quality protein content Pelshenke test	
F5 ⟶ Fm	- idem -	-grain yield (dry matter) -grain quality: protein content Pelshenke test Zeleny sedimentation test Chopin alveograph test

Table 4. Prolamin study on polyacrylamide gel electrophoresis according to the Zillman and Bushuk method (1978).

	Solutions		
Gliadin extraction: (during 2 hours)	2 chloroethanol	25	%
	Pyronin G	0.02	%
	Saccharose	30	%
Electrophoresis buffer:	Aluminium lactate	0.0085	M
	Lactic acid	0.0375	N
	pH 3,2		
Staining solution: (during 48 hours)	Coomassie blue R250	0.5	%
	Ethanol	5	%
	T C A	12	%
Destaining solution:	T C A	12	%
Gel solution:	Acrylamide	6	%
	bis Acrylamide	0.3	%
	Ascorbic Acid	0.1	%
	Ferrous sulfate	0.0025	%
	Aluminium lactate solution	5	%
	Containing:		
	Aluminium lactate	0.17	M
	Lactic Acid	0.75	N
	pH	2.5	

Equipment

Slabe gel electrophoretic apparatus as described by Zillman and Bushuk (1978).

Characteristics of selected lines: -- Lines coming from the cross studied in 1980 are in the F_{11} generation (10 generations of inbreeding). The main agronomical and physiological characteristics of the best selected lines are presented in Table 5.

The lines possess short stature, early heading date for French climatic conditions, satisfactory resistance to black rust but diverse behavior for stripe and leaf rust resistance (for the physiological races at Clermont-Ferrand), moderate susceptibility to powdery mildew, and high susceptibility to eyespot disease. Their technological characteristics for French breadmaking techniques are high to very high.

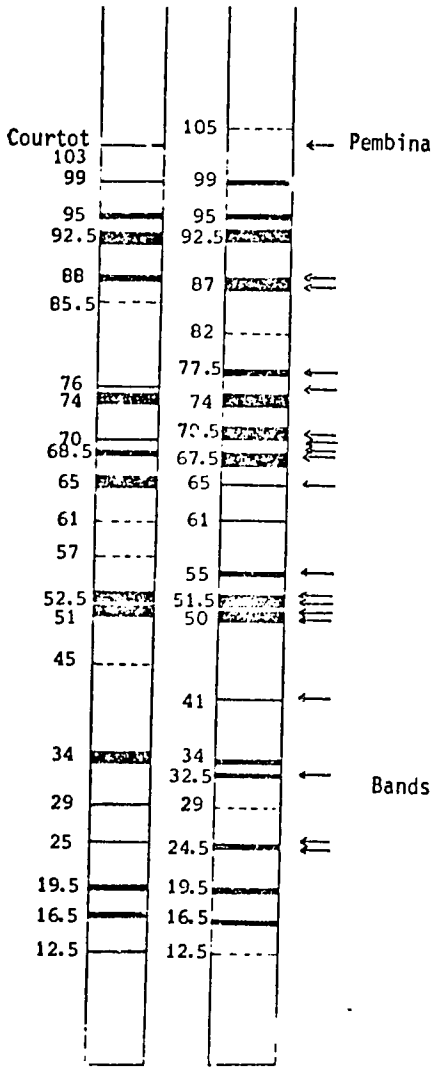
Table 6 shows protein production results (kg per ha) during four trial years at Clermont-Ferrand. The improvement obtained in breeding jointly yield and protein content gives us for the C 235-3-1 genotype for example, a significant increase depending on year of 11.4 to 46.0 per cent compared with checks. As shown in Table 7 the gains observed come from protein content improvement together with yield higher or equal to those of checks.

SCHEME I

Calculation principles of dissimilarity index between two genotypes from prolamin electrophoregrams

$$\frac{\text{total number of bands by which the two electrophoregrams differ (mobility or intensity)} \quad (1)}{\text{total number of bands observed on the two electrophoregrams} \quad (2)}$$

Example



$$\frac{(1) \quad 19}{(2) \quad 34} = 0.558$$

Bands significantly different are marked by arrows

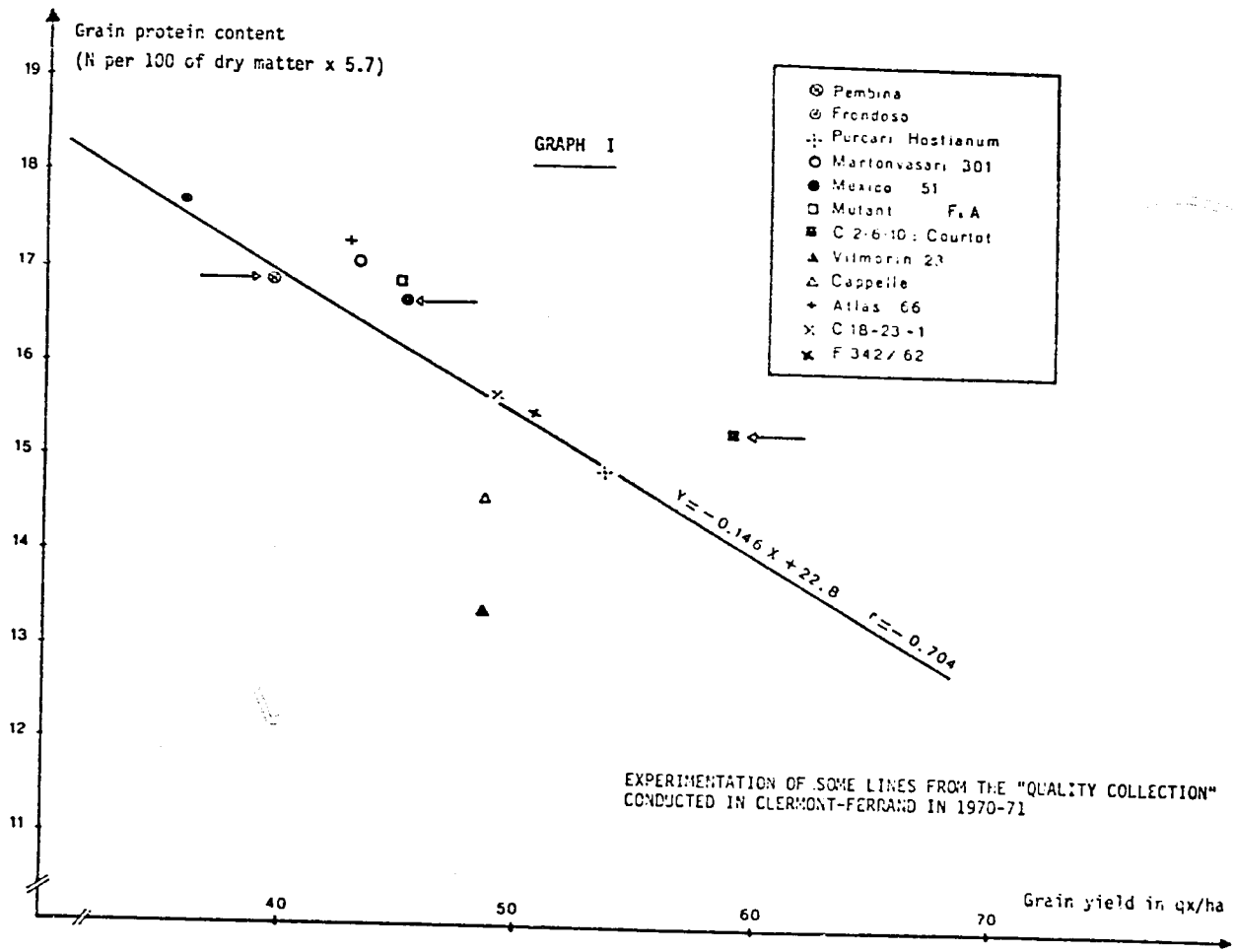

Grain protein content
(N per 100 of dry matter x 5.7)
19
18
17
16
15
14
13
12
11
GRAPH I
Pembina
Frondoso
Purcari Hostianum
Martonvasari 301
Mexico 51
Mutant F. A
C 2-6-10 : Courtot
Vilmorin 23
Cappelle
Atlas 66
C 18-23-1
F 342/62
Y = - 0.146 X + 22.8
r = - 0.704
EXPERIMENTATION OF SOME LINES FROM THE "QUALITY COLLECTION"
CONDUCTED IN CLERMONT-FERRAND IN 1970-71
40
50
60
70
Grain yield in qx/ha

Table 5. Main physiological, agronomical and technological characteristics of lines selected from a Mexico 51 - Courtot x Pembina-Courtot cross grown in Clermont-Ferrand for 4 years (1975-76, 1976-77, 1977-78 and 1978-79).

	Heading date (a)	Height CM (b)	Cercosporella Herpotrichoides (c)	Erysiphe graminis (d)	Puccinia striiformis (e)	Puccinia graminis (f)	Puccinia recondita (g)	Chopin alveograph test W (h)	Chopin alveograph test G (i)	Chopin alveograph test P/L (j)	Zeleny sediment. test (k)	Pelshenke test (l)
Clement (T)	+ 8	108	MR*	4	4	4	3	64.5 (20.7)	16.4 (1.6)	0.98 (0.30)	16.2 (5.2)	22.8 (3.3)
Courtot (T)	5/25th0	65	S*	3	6	1	1	226.2 (41.3)	25.1 (2.6)	0.52 (0.15)	39.5 (10.9)	140.0 (21.8)
C 235-3-1 ...	-	65	S	4	3	1	3	251.7 (28.3)	22.8 (1.7)	0.65 (0.16)	40.0 (5.2)	124.3 (17.1)
C 235-3-5 ...	+ 1	65	S	4	4	1	3	240.7 (12.6)	23.6 (1.4)	0.60 (0.16)	38.0 (5.7)	127.3 (16.9)
C 240-7-4 .(1)	+ 2	65	S	4	2	1	-	267.0 (12.0)	22.7 (0.3)	0.70 (0.03)	38.5 (5.5)	137.0 (5.0)
C 240-14-7 ...	+ 2	66	S	3	2	1	6	270.0 (54.1)	23.7 (1.9)	0.66 (0.16)	37.3 (4.0)	115.0 (17.7)
C 240-14-8 ...	+ 1	68	S	4	2	1	6	307.7 (38.3)	24.3 (2.0)	0.63 (0.11)	52.3 (9.3)	168.8 (15.1)
C 247-7-4 ...	-	68	S	3	4	1	4	326.0 (44.4)	25.3 (2.5)	0.66 (0.28)	52.3 (11.5)	141.3 (4.7)
C 248-8-1-5 ..	+ 3	68	S	4	3	4	3	321.7 (20.5)	21.8 (1.0)	0.92 (0.20)	51.5 (8.6)	185.5 (32.0)
C 253-1-4-3 (2)	+ 2	73	S	4	4	2	1	240.3 (49.5)	22.5 (1.7)	0.67 (0.14)	36.3 (7.6)	108.7 (13.6)

(a), (b), (h), (i), (j), (k), (l) : mean on the 4 years, (-) Standard deviation. (d), (e), (f), (g) : highest note during the 4 years. (c) : only one observation with controled conditions in Rennes.

1 = resistant .....9 = highly susceptible

* MR = moderately resistant - S = susceptible

(1) grown 2 years in 1975 and 1976

(2) grown 3 years in 1975, 1976 and 1978

Table 6. Protein production (at Clermont-Ferrand) of some selected lines compared to the check varieties "Clement" and "Courtot".

Line/ variety	Harvest 1975 (2)	(3)	Harvest 1976 (2)	(3)	Harvest 1977 (2)	(3)	Harvest 1978 (2)	(3)
Clement	777		746		413		803	
	100 = 77.5		100 = 807.0		100 = 417.5		100 = 779.5	
Courtot	778		868		422		756	
Selected from a Mexico51-Courtot x Pembina-Courtot cross:								
C 235.3.1...	866	111.4	910*	112.8	590*	141.3	1138*	146.0
C 235.3.5...	-	-	926*	114.7	587*	140.6	1104*	141.6
C 240.7.4...	856	110.1	927*	114.9	(1)	(1)	-	-
C 240.14.7...	819	105.3	889*	110.2	549*	131.5	1015*	130.2
C 240.14.8...	872	112.1	881*	109.2	543*	130.0	930*	119.3
C 247.7.4....	860	110.6	939*	116.4	493*	118.1	955*	122.5
C 248.8.1.5..	834	107.3	956*	118.5	470	112.6	964*	123.7
C 253.1.4.3..	903*	116.1	984*	121.9	(1)	(1)	1100*	141.1

(1) unadequate seed quantity for sowing. (2) protein production in kg/ha. (3) p.100 of theorical check.
* significantly higher than the theorical check $\frac{\text{"Courtot"} \quad \text{"Clement"}}{2}$

Table 7. Grain yield and protein content of some selected lines compared to the check varieties Clement and Courtot.

Variety	Harvest 1975 (1)	Harvest 1975 (2)	Harvest 1976 (1)	Harvest 1976 (2)	Harvest 1977 (1)	Harvest 1977 (2)	Harvest 1978 (1)	Harvest 1978 (2)
Courtot	64.3	12.1	55.8	15.6	32.7	12.9	57.9	13.1
Clement	61.9	12.6	46.7	16.0	36.4	11.3	70.5	11.4
C 235.3.1	59.3	14.6*	55.0	16.5*	41.1*	14.4*	76.9*	14.8*
C 240.14.8	61.6	14.1*	55.3	15.9	42.3*	12.9	71.9*	12.9*
C 253.1 (4)	66.1	13.7*	59.1*	16.7*	-	-	85.3*	12.9*
C 247.7 (4)	58.0	14.9*	55.1	17.0*	35.3	14.1*	71.0*	13.5*

(1) = grain yield in qx/ha at 0% of dry matter. (2) = protein content (nitrogen % of dry matter x 5.7). * = significantly higher than the theorical check $\frac{\text{Courtot + Clement}}{2}$

Multilocation trial results for C 240-14-8 line in 1977-78, a year when grain yield was exceptionally high and when correlation with mean protein content was low, are presented in Table 8 (grain yield-protein content and protein production per ha) and in graph 2 (protein content).

Graph 2 presents, according to the Finley-Wilkinson model, a characterization of each genotype with protein content of each genotype at each location in relation to the mean value of genotype protein contents at each location (protein content location value). This experimentation confirms for the crude grain protein content character in spite of the low mean level, the superiority of the line C 240-14-8 over the classical line Top, but not over Courtot. However, it must be noticed that the average yield of Courtot for all trials is only 51.8 q/ha whereas that of C 240-14-8 is 55.9 q/ha (at 0% H_2O).

It seems to us quite clear that the high productivity and good ability to store proteins in the grain of C 240-14-8 resulting in high protein production per hectare can be expressed only in propitious environmental conditions, particularly without accidents during the vegetative period, as is the case at Clermont-Ferrand, Colmar, Mons and Rennes (fungicide treatment) in 1977-78 (see Table 8).

Prolamin electrophoregrams on polyacrylamide gel shown on scheme 2 are characteristic of the genotypes. Their expression, not being modified qualitatively by the environment, gives us information on following points: Using these electrophoregrams as biochemical markers, we can see that most parental bands can be found in several selected lines. However, some bands are different in the offspring compared with parental lines, either for mobility: Gamma 7 in diagram 4, Beta 12 in diagrams 5-6-7, Alpha 3 in diagrams 4-6-8-9-10, and Alpha 10 in diagrams 6-8-9-10; or for intensity: the Omega 14 band is in trace state for Courtot and more marked in diagram 7.

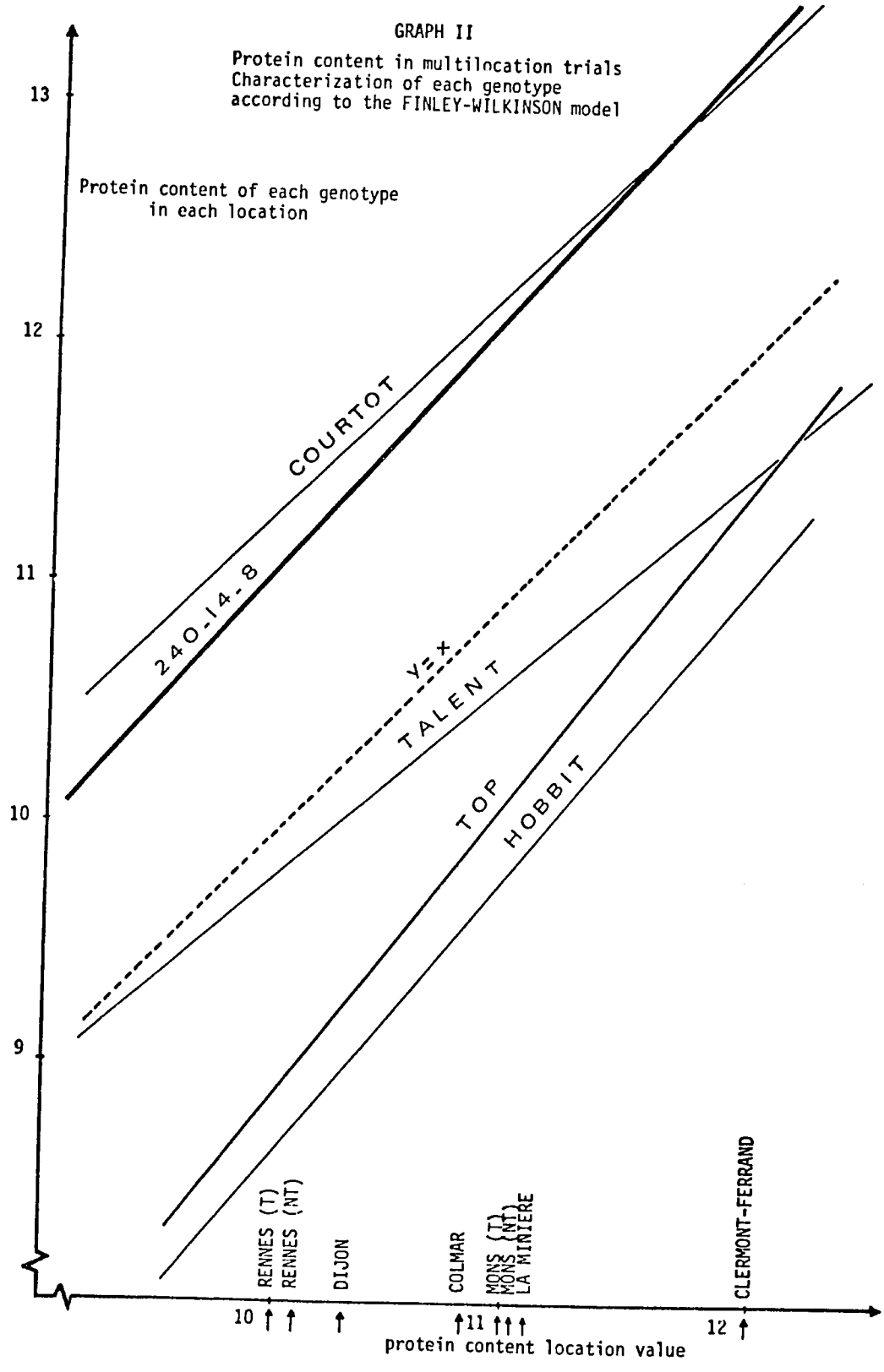

GRAPH II
Protein content in multilocation trials
Characterization of each genotype
according to the FINLEY-WILKINSON model
Protein content of each genotype
in each location
13
12
11
10
9
COURTOT
240-14-8
Y=X
TALENT
TOP
HOBBIT
RENNES (T)
RENNES (NT)
DIJON
COLMAR
MONS (T)
MONS (NT)
LA MINIERE
CLERMONT-FERRAND
10
11
12
protein content location value

Table 8. Multilocation trials in 1977-78.

Varieties	Clermont Ferrand			Colmar			Dijon			La Miniere			Mons (T)			Mons (NT)			Rennes (T)			Rennes (NT)		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Top (Check line) = 100	.8	11.4	807	66.9	10.1	676	55.9	9.5	531	66.9	9.6	642	63.6	10.2	642	57.5	10.8	621	65.1	8.7	566	56.0	9.0	504
Courtot	84*	115*	97	84*	119*	100	68*	125*	85	80*	132*	106	87*	112*	107	96	110*	106	75*	125*	95	84	127*	106
C 240-14-8	105	116*	121	92	123*	113	66*	124*	82	78*	125*	98	95	122*	117	100	110*	110	94	126*	119	76*	120*	91

(1) = Yield in qx/ha of dry matter.
(2) = Grain protein content (Nitrogen p 100 of dry matter x 5.7)
(3) = Protein yield in kg/ha

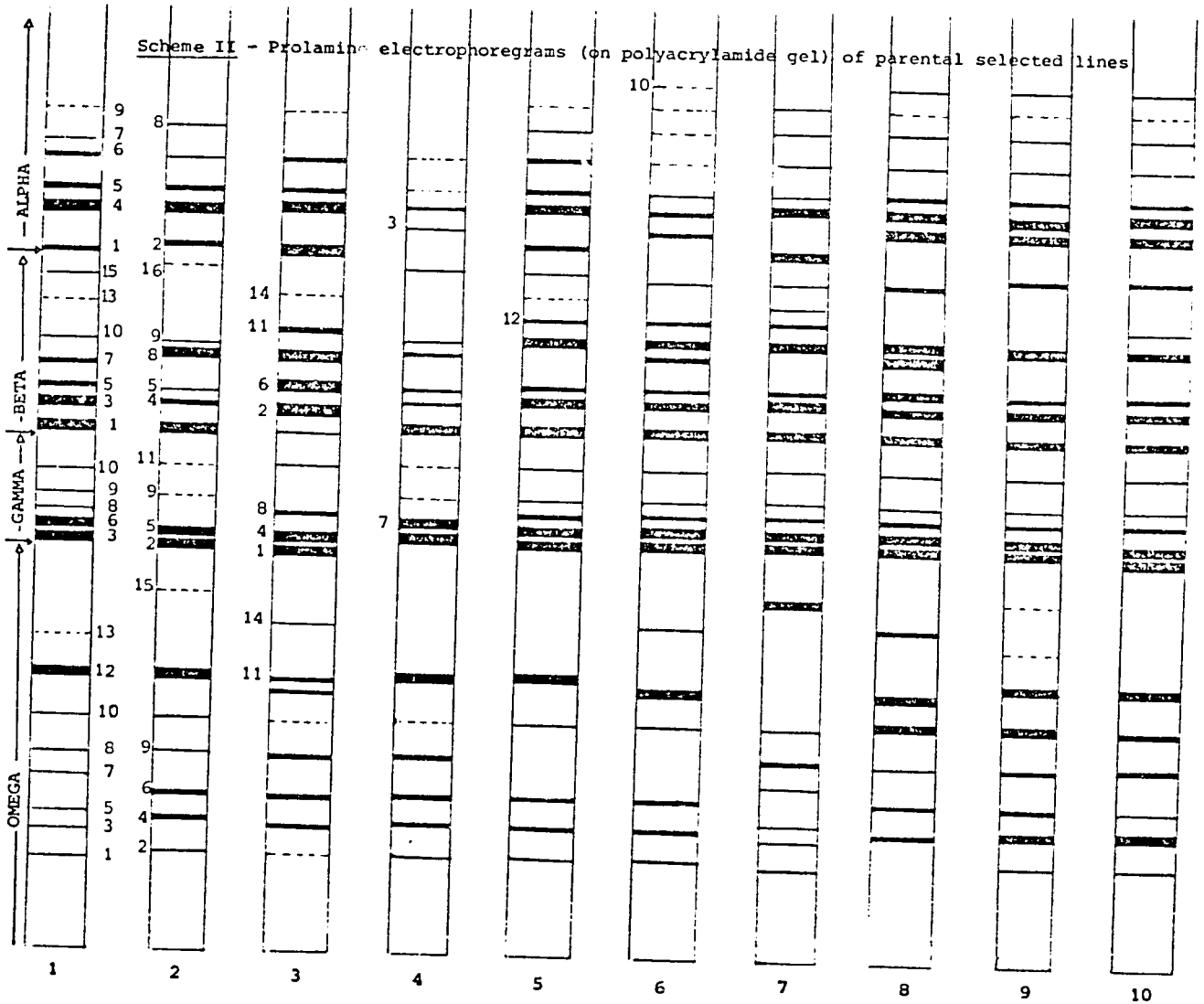
Expressed in % of the Check variety "TOP"

(T) = Treated
(NT) = Non treated

by fungicide

* Yield or protein content significatly different of the check "Top".

Scheme II - Prolamin electrophoregrams (on polyacrylamide gel) of parental selected lines



1 = Mexico 51
2 = Courtot
3 = Pembina
4 = C 231-6-5
5 = 235-3-1
235-3-5
240-7-3
240-7-5
6 = 240-14-3
240-14-7
240-14-8
7 = 247-7-3
247-7-4
248-8
8 = 250-3-2
9 = 253-1-4-3-2-2
10 = 253-1-4-3-2-4

These results could appear to be in disagreement with what we know about the heredity of gliadin bands that 1) every band is governed by one allelic pair (Mecham and Kasarda 1978) or by one or two allelic pairs (unpublished results), 2) genes responsible for each band appear to act as codominants in F_1 genotypes. The main explanations for modified mobility could be the following: 1) bindings between proteins and carbohydrates or small conformational arrangement modifications of protein coming from pH changes (perhaps the case for the Gamma 7 band), or 2) modified electric charge of protein. Uncontrolled cross pollination could explain these modifications but would introduce more differences than those which are observed on these diagrams. Thus this hypothesis can be discarded.

Genetical distance study between these genotypes (see Table 9) measured by a dissimilarity index evaluated from the diagrams observed permit us to say that: 1) Mexico 51 and Courtot lines are quite close but both are relatively distant from Pembina. 2) Selected lines are more distant from Mexico 51 and Pembina than from Courtot. 3) Genetical distances between selected lines vary from 0 (identical diagrams) to 0.68.

In an earlier study (in publication), we showed a correlation, weak but significant, between relative concentrations of α and β gliadins and genotype protein contents. We failed to demonstrate an analogous correlation with the material studied here. This observation perhaps comes from the narrow genetical variability retained at the end of the selection described here.

Discussion and Conclusions

The improvement obtained in selecting jointly for grain yield and protein content in the environment of Clermont-Ferrand is about 10 to 45% for protein yield (better crude protein content together with high grain yield) depending on genotype and year, compared with the best check varieties.

We consider that genetical progress for protein content, for a given grain yield, is about 1 to 2 percentage points for selected lines compared to a standard of good agronomical value such as the "Clement" variety in Clermont-Ferrand conditions.

Multilocation trials grown in the northern part of France seemed to minimize progress noted at only one location (Clermont-Ferrand).

A hypothesis which could explain this observation is the following: Growing nurseries and trials in only one location where yield and protein content are often very high could favor the selection of genotypes which profit from favorable genotype x environment interactions resulting in high protein level and yield character expression. For some characters such as short stature, early heading date, prolamin electrophoregram, selected

Table 9. Dissimilarity index (see calculation principle in scheme I) for parental and selected lines obtained from a Mexico 51 - Courtot x Pembina-Courtot cross

Diagram number	Mexico 51 1	Courtot 2	Pembina 3	4	5	6	7	8	9
1									
2	0.46								
3	0.67	0.56							
4	0.60	0.28	0.63						
5	0.57	0.26	0.58	0.46					
6	0.59	0.42	0.54	0.40	0.31				
7	0.38	0.64	0.68	0.68	0.47	0.45			
8	0.59	0.43	0.56	0.55	0.43	0.15	0.50		
9	0.57	0.36	0.54	0.39	0.21	0.30	0.52	0.24	
10	0.64	0.47	0.50	0.50	0.29	0.37	0.56	0.40	0.18
Average distance with offspring	0.56	0.41	0.58						

lines were nearer to the variety Courtot than the other progenitors. Two possible explanations for these observations are: Courtot participates doubly compared with the other lines in the original cross. Courtot and the selected lines were obtained in the same environment (perhaps homogamy for environmental adaptation).

References

P. d'Assignies 1979. Le marche francais des cereales en 1979-80. Le Producteur Agricole Francais, 55eme annee, N° 260, 2e de novembre 79: 10-11.

Bushuk, W., R.R. Zillman, 1978. Wheat cultivar identification by gliadin electrophoregrams. I-Apparatus, method and nomenclature. Can. J. Plant Sci., 58: 505-515.

Finley, K.W., and G.N. Wilkinson, 1963. The analysis of adaptation in a plant breeding programme. Aust. J. Agric. Res., 14: 742-54.

Johnson, V.A. 1978. Breeding for yield and protein content in Hard Winter Wheat. Cereal Foods World, February 1978, Vol. 23 N° 2, 84-86.

Mecham, D.K., D.D. Kasarda and C.O. Qualset, 1978. Genetic aspects of Wheat Gliadin Proteins. Biochemical Genetics, 16: 831-853.

RECURRENT SELECTION FOR GRAIN PROTEIN CONTENT AND GRAIN PROTEIN YIELD IN SPRING WHEAT

F. H. McNeal and C. F. McGuire
United States

Abstract

A recurrent selection program to increase grain protein in spring wheat, Triticum aestivum L., was started at Bozeman, Montana, in 1967 using nine single crosses. Grain from F_3 progeny rows of these crosses was evaluated from a 1969 planting using the Udy dye binding method for protein determination. The two lines judged best for protein content from each of the nine crosses were intercrossed in all possible combinations in 1970 to provide material for a second cycle of testing.

Seed from F_3 progeny rows of the second cycle was evaluated for grain protein in 1973. Selections with the highest protein content were then compared with check cultivars 'Newana' and 'Olaf' in different environments in succeeding years to determine if progress was evident. Of 295 of these selections evaluated in 1977 at two locations, the average protein content (%) of every selection exceeded the protein content of both check cultivars, but only two selections had protein yields (g/16 ft.) greater than that of Newana; none exceeded the protein yield of Olaf.

We re-selected the second cycle selections in 1973, basing selection this time on protein yield. When these selections were evaluated in 1979 field plots at Bozeman and harvested on the basis of agronomic attractiveness, all but three of 193 selections had protein contents higher than both check cultivars, and in addition, more than 40% of the selections had protein yields higher than either check.

These data suggest that selecting for increased protein yield will be more productive than selecting for increased protein content.

Protein evaluation of the U.S. Department of Agriculture World Wheat Collection was initiated at Bozeman, Montana, in 1963. The first year, 1000 cultivars selected at random from 68 states and foreign countries were evaluated for grain protein. In 1964, another 1000 entries were evaluated.

About this time, Nebraska researchers began to expand their protein evaluation program, so the decision was made to concentrate Montana efforts on a recurrent selection program to increase the protein content of hard red spring wheat. High protein parents were selected from the cultivars which had been under test, with the hope

AR/SEA, USDA, and the Montana Agricultural Experiment Station, Bozeman

of having a wide range of genotypes.

Eleven cultivars with high protein content were selected from nine countries, including the United States, to be used as parents (Table 1). PI 176223 from India is a sister selection of Nap Hal, PI 176217, a high protein cultivar used extensively by Nebraska in its protein breeding program.

Table 1. Protein parents and their origin.

Parent	Origin
PI 176223	India
PI 255141	Austria
PI 175517	Finland
PI 134880	Portugal
PI 125000	Turkey
Fronteira	Brazil
Frondoso	Brazil
PK 176	Mexico
PI 272377	Hungary
Gilmore	U.S.
MT 6618	U.S.

Nine crosses were made in the field at Bozeman in 1967 (Table 2). Seed from the F_3 progeny, grown in single 1.5 m rows in 1969, was evaluated for grain protein content. The spread in protein was only 2.7% in cross 6735, but it varied upward to 6.4% in cross 6724, which has PI 176223 as one of the parents. This protein spread within each of the crosses suggested the presence of protein differences, so a second cycle of crossing was started.

Table 2. Crosses made in 1967 and protein percentages of seed from F_3 progeny rows grown in 1969.

Cross	Cross No.	F_3 rows grown	Protein range, %
Centana/PI 176223	6711	1476	13.5-18.1
PI 125000/Centana	6712	1572	14.3-18.1
Centana/PI 175517	6713	1632	14.2-17.9
PI 255141/Centana	6721	1596	14.2-18.3
Gilmore/PI 176223	6724	440	11.5-17.9
PK 176/Frondoso	6726	273	12.7-17.3
PK 176/Fronteira	6727	704	12.5-17.6
MT 6618/PI 272377	6735	452	14.6-17.3
PI 134880/Centana	6737	1197	14.2-18.6

The two selections with the highest protein percentages were chosen from each of the original nine crosses, and these were used in a diallel scheme of crossing in the field in 1970. Of the possible 153 crosses from such a diallel, crossed seed was obtained from 149. F_3 progeny rows from these 149 second-cycle crosses were grown in the field in 1973 and the protein content was determined on seed harvested from these rows.

Second-cycle selections with the highest protein percentages were then compared with first cycle selections to determine the extent of progress in obtaining higher protein percentages. To do this, seed produced from the 10 highest protein selections from F_3 progeny rows of each cross of both the first and second cycles was planted in 1975. Seed produced in 1975 was evaluated for protein content (Table 3). Differences in protein content show that the second cycle percentages were always highest, ranging from .3 to 2.4%. These data suggest that progress has been made in recombining high protein genotypes.

Table 3. Protein content of first and second cycle selections field tested in 1975.

Cross No.	Protein, %		
	1st cycle	2nd cycle	Diff.
6711	16.6	17.5	.9
6712	17.3	18.3	1.0
6713	16.2	18.6	2.4
6721	18.1	19.0	.9
6724	18.1	18.5	.4
6726	16.9	17.5	.6
6727	16.7	17.0	.3
6735	16.4	17.4	1.0
6737	17.5	18.1	.6

In 1977, the parents, check cultivars 'Newana' and 'Olaf', and second cycle selections with the highest protein percentages, were grown in replicated nurseries at two locations. The checks, Newana and Olaf, are semidwarf cultivars grown commerically in the U.S. hard red spring wheat area. Protein content and protein yield were obtained for the parents and check cultivars (Table 4). A comparison of protein data reveals that check cultivars Newana and Olaf have the lowest protein percentages, but their protein yields (protein percentage X grain yield) are higher than the yields from any of the parents. However, if we assume that protein percentage is a genetically controlled trait, it should be possible to select lines from a crossing program that have both high protein content and high grain yield.

Table 4. Protein content and protein yield of parents compared to check cultivars.

Entry	1977 Protein Data %	Kg/ha
Parents:		
PI 176223	17.9	471
PI 255141	17.9	415
PI 175517	17.8	328
PI 134880	17.8	492
PI 125000	17.2	396
Fronteira	17.1	412
Frondoso	17.0	451
PK 176	16.4	459
PI 272377	16.3	463
Gilmore	16.2	449
MT 6618	15.6	442
Checks:		
Newana	15.6	503
Olaf	15.6	576

In addition, 295 of the highest protein selections from the second cycle were compared with check cultivars Newana and Olaf in the 1977 replicated trials. The average protein percentage of each selection exceeded the protein percentage of both check cultivars, but only two of the 295 selections had protein yields greater than that of Newana. None exceeded the protein yield of Olaf.

After baking tests on the 295 selections, 16 were chosen as having the best baking quality and highest protein content (Table 5). The average protein data of the 11 parents and 16 selections are compared to checks Newana and Olaf. This simply confirms what has already been observed, that the check cultivars have the lowest protein percentages, but the highest protein yields. These data suggest that selection for protein content might provide progress in improving protein percentages, but little, if any, progress is evident in improving protein yield.

Table 5. Data from 16 lines selected for grain protein percentage.

Entry	1977 Protein Data %	Kg/ha
Average of 11 parents	17.0	434
Average of 16 selections	17.5	458
Newana	15.6	503
Olaf	15.6	576

The decision was then made to re-select second cycle lines of 1973, basing selection this time on protein yield, rather than protein content. Nearly 1500 lines were selected and field tested in two replications of 2-row plots at Bozeman in 1979. Each line was evaluated for agronomic attractiveness, and only 193 of the best appearing lines were harvested. All but 3 of the 193 selections had protein contents higher than check cultivars Newana and Olaf, and in addition, more than 40% of the selections had protein yields higher than either check.

After baking data were available, 40 of the 193 lines were selected as having the best loaf volume and grain and texture scores. Protein data for these 40 selections are shown in Table 6. The highest, the lowest, and the average protein yields are compared to those of the checks. The average protein yield is higher than that of either check, and the highest is 186 kg/ha higher than Olaf.

Table 6. Data from 40 lines selected for grain protein yield.

Entry	1977 Protein Data	
	%	Kg/ha
Highest protein yield	17.3	807
Lowest protein yield	16.6	519
Average of 40 selections	17.3	640
Newana	15.6	514
Olaf	15.7	621

The parental and selection data from 1977, the selection data from 1979, and the 1977-1979 averages for Newana and Olaf have also been compared (Table 7).

Table 7. Selecting for protein percentage vs protein yield.

Entry	Protein Data	
	%	Kg/ha
Parents, Average (11)	17.0	434
1977, Average (16)	17.5	458
1979, Average (40)	17.3	640
Newana, Avg. 77-79	15.6	508
Olaf, Avg. 77-79	15.6	598

Protein percentages of the selections are higher than those of both the checks and the parents. However, the mo t obvious improvement is in protein yield, where the average from selecting for protein yield is 182 kg/ha higher than the average from selecting for protein content, with little or no loss in protein percentage. If these data can be verified in uniform field tests in 1980, then it should be obvious that selecting for protein yield may be more productive than selecting for protein content, when choosing high yield-high protein lines.

PHYSICAL AND CHEMICAL PROPERTIES OF GRAIN LAYERS FOR DURUM AND SOFT WHEAT VARIETIES.

A. M. Khorshid and H. M. El Attar
Egypt

Abstract

The Egyptian soft wheat variety Giza 156 and Syrian durum wheat variety Hurani were debranned and five layers of each grain were obtained by using a special machine. The outer layers were highest in protein content and lysine. The outer layers of durum grains were higher in protein than those in the soft grains. Flour of the outer layers has higher water absorption and longer mixing time for forming dough than the inner layers. Flour from the outer layers can be recommended for preparing baby foods and diabetic bread blends.

The best milling conditions are those processes characterized by good and clean separation of bran from endosperm since the presence of any particles of the bran (containing much minerals and fibers) will go through the sieves to the flour and will be considered as flour. Therefore, the presence of fine bran particles in the flour affects its quality as it increases the ash and fiber contents of the flour and makes its color darker. Also any particles of endosperm in contact with the bran removed during milling will decrease flour extraction because they are considered as bran (Coply et al, 1966 and Theodor et al, 1970).

Whole wheat flour is not widely used for direct human consumption. Usually, the bran is separated before or during milling. Recently a method of wheat milling was developed which depends on crushing the wheat kernel and separating the bran by successive sieving. Also the process of debranning which includes mechanical separation of the bran by a laboratory rice polisher was introduced on laboratory scale as a method for obtaining flour with specified extraction percentages (Khorshid 1976). Debranned kernels can be milled directly into flour with no sieving in one step. The same machine can be used also for separating successive layers from the debranned grains.

Wheat grain components such as protein, starch, fat, ash, etc. are not distributed evenly throughout the whole grain. The bran and germ are richer in protein than the endosperm alone. It has been reported that the center of the kernel is not as rich in protein as the outer layers (Kent Jones and Amos 1967). Protein is not evenly distributed throughout the endosperm, and even its quality varies according to where it is found in the grain. There is a higher protein percentage near the bran coating but the quality

is better near the center (Fance 1972). Stevens et al (1963) found that the biological value of the protein in the germ and aleurone is higher than that of the endosperm proteins. The lysine content is about 2.5 times as large in the protein of these tissues as it is in that of endosperm. Weggle et al (1967) found that only lysine could be shown to be significantly higher in high extraction flours.

The aim of this investigation was to determine the ideal conditions for clean bran removal, then to fractionate the wheat kernel to five successive layers (after the separation of outer layer i.e. bran) and to study the chemical composition and rheological properties of each layer.

Materials and Methods

Materials

The Egyptian soft wheat variety Giza 156 and Syrian durum wheat variety Horani were used in this study.

Debranning

A laboratory rice mill model "Universal" was used for debranning wheat grains. For the Giza 156 variety, the grains were soaked for one min.; tempering times were 1 and 2 min.; and debranning times were 1/2, 1, 1-1/2 and 2 min. For Hurani grain, soaking time was one min., tempering times 2 and 4 min. and debranning times 1/2, 1, 1-1/2, 2, 2-1/2 and 3 min. Dry debranning was achieved without soaking or tempering for the same debranning times. The ideal conditions for clean bran removal obtained in the study were used to separate 12% of the kernel outer layers which represent the bran. After that, four layers from the debranned kernel were separated by using the same machine. Each layer represents 10% from the total wheat grain weight. The last (inner) part (fifth layer), representing 48% from the total grain weight, was milled separately in a micro laboratory mill to obtain flour.

Chemical Analyses

Moisture, crude protein (by Kjeldahl), ash, fat and starch contents of wheat grains and their layers were determined according to the official methods of analysis, AACC, 1969.

Lysine estimation was done using the colorimetric method designed by Tsai and modified by Villegas (1971).

Physical Tests

Farinograph tests were conducted according to the procedures outlined in Cereal Laboratory Methods, A.A.C.C. (1969). Color of flour was measured by a Kent-Jones color grader apparatus.

Results & Discussion

Process of Debranning and Its Efficiency

With regard to efficiency of debranning, the more efficient method or pretreatments are those that produce maximum yield of flour with low ash and fiber contents and of whiter color.

Wheat grain tests were divided into two parts. In the first part grain was debranned without soaking. In the second part, it was debranned after one minute soaking in water at room temperature and leaving the grain for several minutes as tempering time. The soaked and non-soaked grain of Giza 156 and Hurani wheat varieties was debranned with different times of debranning. The debranned kernels were milled into flour and the yield of debranned grains was considered as flour extraction. Data presented in tables 1 & 2 show the relationship between flour extraction, ash and fiber contents, and color degree. From the results obtained, it was noticed that soaking and tempering time increases the efficiency of debranning for both varieties although optimum time depends on variety. A positive correlation was found between flour extraction, color degree, ash and fiber contents. Flour extraction of 88% of Giza 156 obtained by different debranning methods gave different flour properties. The best flour from the same extraction was obtained by soaking the grains for one minute, tempering for one minute and debranning for 1-1/2 minute. Under these conditions, the best and cleanest bran removal was achieved. For Hurani grain, and because of its hardness, the tempering and debranning times were increased up to 4 and 3 minutes respectively. The best bran removal in order to obtain the same flour extraction as in Giza 156 (about 88%) was achieved by soaking the grain for one minute, tempering for 4 minutes and debranning for 1-1/2 minutes. Such a short period of soaking and tempering was sufficient for the bran of wheat kernels to absorb enough water that did not penetrate into the endosperm; hence the debranning was quite efficient.

Properties of Kernel Layers

The ideal conditions of clean bran removal obtained in this study (1 min. soaking, 1 min. tempering and 1-1/2 min. debranning for Giza 156 wheat grain and 1 min. soaking, 4 min. tempering and 1-1/2 min. debranning for Hurani wheat grain) were used to separate 12% of the outer layers of the kernel which represent mainly the bran. From the debranned grains, five layers were separated and each one of them represents ten percent of the whole kernel except the fifth (inner) layer which represents 48% of the whole kernel.

Table 1. The relation between debranning conditions and properties of flours obtained from debranned grains of Giza 156 wheat variety.

Soaking	Without soaking				With soaking							
Tempering time (T.T.)	---------				1 minute T.T.				2 minutes T.T.			
Debranning time in minutes	½	1	1 ½	2	½	1	1 ½	2	½	1	1 ½	2
Flour extraction %	92.2	88.1	84.2	80.2	94	91.8	87.8	82.7	91.3	87.8	83.3	80.2
Color degree	13.7	11.60	10.4	9.80	13.30	11.90	10.40	10.0	12.0	10.50	10.20	9.45
Ash %	1.48	1.29	1.15	1.03	1.49	1.29	1.11	1.06	1.33	1.16	1.11	0.97
Fiber %	1.9	1.6	1.3	1.02	2.08	1.60	1.4	1.09	1.63	1.42	1.18	0.92

Table 2. The relation between debranning conditions and properties of flours obtained from debranned grains of HURANI wheat variety.

Soaking	Without soaking						With soaking											
Tempering time T.T.							2 minutes T.T.						4 minutes T.T.					
Debranning time in minutes	½	1	1 ½	2	2 ½	3	½	1	1 ½	2	2 ½	3	½	1	1 ½	2	2 ½	3
Flour extraction %	93.2	91.8	90.0	89.1	86.3	84.4	93.9	90.3	88.6	86.5	84.1	82.1	92.3	90.2	88.5	85.8	83.7	81.8
Color degree	13.90	13.20	13.0	12.90	12.20	11.90	13.10	12.50	12.0	11.60	11.20	10.65	12.50	12.0	11.80	11.0	10.60	10.0
Ash %	1.7	1.56	1.48	1.43	1.35	1.27	1.54	1.34	1.30	1.27	1.20	1.11	1.46	1.29	1.27	1.2	1.12	1.0
Fiber %	2.46	2.17	2.04	1.97	1.88	1.37	2.19	1.8	1.64	1.46	1.29	1.19	1.93	1.6	1.51	1.32	1.15	0.90

The five layers separated individually from Giza 156 and Hurani wheat varieties after separation of the outer layer (bran) varied in their chemical composition and rheological properties. Table 3 presents the chemical composition of debranned kernel layers in comparison with whole grain of Giza 156 and Hurani wheat varieties. It was found that ash, protein and fat contents of Giza 156, decreased gradually from the outer to the inner layers, while starch content increases. Ash content decreased by 1.5% from the first to the fifth layer. The largest decrease in ash content was found between the first and the second layers. The high ash content of the outer layers is due to minerals concentrated in germ and outer layers. Also, it can be noted that the first layer contained the highest percentage of protein in comparison with the other layers, while the fifth layer contained the lowest percentage (9.8%). The difference between the two layers was 6.1%. The most noticable decrease in protein content was found between the first and the second layers. Also fat content decreased gradually from the outer to the inner layers with the highest decrease occurring between the first and the second one.

On the other hand, starch content increased gradually from the outer to the inner layers. The highest starch content was found in the fifth layer, while the lowest was found in the outer one. The difference between the two layers is 15.5%. This large increase in starch content in the inner layer is connected with the decrease in other components such as protein, fat, fibers.. etc..

Hurani decorticated grains showed the same trend. Ash, protein and fat contents decreased gradually from the outer to inner layers, and starch increased. Protein content in the first (outer) layer was very high (25.4%), while in the fifth one (inner) it was about one half (12.2%) in amount. Starch content in the first layer was extremely low(53.7%). The difference in starch percentage between the first layer and the fifth one was 21.7%. Data mentioned above agree with Pomeranz, 1971; Hinton, 1959; and Orth and Mander, 1975.

Lysine in Grain Layers

From Table 3 it is clearly noted that lysine content in the protein of the grain layers decreases from the outer layers to the inner ones. The first (outer) layer in Giza 156 and Hurani grain is the richest layer in lysine content 4.9 and 4.42 per 100 g. protein, respectively. The poorest layer is the fifth (inner) one. Such results agree with Stevens, 1963. Lysine content in proteins of Hurani grains (high in protein content) is relatively lower than Giza 156 grains (less protein content). From these results, it can be concluded that lysine is concentrated in the outer layers of the decorticated grains of both Giza 156 and Hurani wheat varieties. Such layers can be recommended in the blends of baby foods and diabetic bread, due to their high protein and lysine contents.

Table 3. Chemical Composition of debranned kernel layers in comparison with the whole grain.

Wheat Variety	GIZA 156					HURANI				
Endosperm Layers	Ash %	Fat %	Starch %	Protein %	Lysine in protein %	Ash %	Fat %	Starch %	Protein %	Lysine in protein %
First Layer	2.21	3.75	62.2	15.9	4.94	3.18	3.71	53.7	25.4	4.43
Second Layer	1.54	2.49	66.9	13.6	4.32	1.77	2.84	61.8	21.5	4.05
Third Layer	1.22	2.05	70.6	12.4	3.68	1.38	2.58	68.4	18.2	3.27
Fourth Layer	1.03	1.52	73.6	11.1	3.06	1.05	1.36	71.1	16.3	2.66
Fifth Layer	0.70	0.83	77.7	9.8	2.28	0.67	0.65	75.4	12.2	2.86
Whole Kernel	1.85	2.24	67.3	11.0	3.11	1.98	2.08	64.5	15.2	2.86

Table 4. Farinograph characteristics of Giza 156 and HURANI Kernel Layers flours.

Wheat Variety	GIZA 156				HURANI			
Endosperm Layers	Water absorption %	Mixing time min.	Stability min.	Weakening B.U.	Water absorption %	Mixing time min.	Stability min.	Weakening B.U.
First Layer	80.0	5.2	1.3	280	88.0	4.3	4.0	260
Second Layer	76.6	3.4	2.2	230	84.0	3.0	3.0	210
Third Layer	77.0	2.3	2.4	215	85.0	3.0	2.3	230
Fourth Layer	77.5	1.5	3.0	210	85.5	2.3	1.3	240
Fifth Layer	67.0	1.0	3.3	150	73.0	1.2	1.3	170

Farinograph Tests

The rheological properties of the wheat grain layers were determined by farinograph tests. Table 4 and Figs. 1 and 2 present the farinograms and data obtained from them. The data showed that the water absorption capacity of the first flour layers of Giza 156 wheat grain (after separation of 12% from the outer layers of the grain) was higher than that of the other layers. This can be due to the presence of higher fiber and pentosans (hygroscropic components), higher percentage of damaged starch granules, and higher percentage of protein in the first layer than in the other layers. The fifth layer clearly gave low water absorption capacity which is considered to be a result of the normal milling of this layer (48% of the whole kernel). Stability of dough is an important property which reflects mainly the gluten quality in dough. From Table 2 it can be noted that the outer kernel layers are of lower stability than the inner layers. The maximum stability was detected in the fifth layer. The weakening of dough as shown in the same table also gives an idea about its strength. The highest weakening (280 B.U.) was noticed in the first layer. The weakening number increased gradually from the first to the fifth layer. The high weakening of the first layer may be due to the low quality of its gluten and the relatively high fiber content in it. For Hurani grain layers, water absorption of the flour obtained from the first layer was very high (88%). It was higher than the water absorption of the same layer in Giza 156 wheat variety. The fifth layer was relatively low in water absorption. Mixing time decreased gradually from the first layer (4.0 min.) to the fifth one (1.2 min.). This shows that development of the dough from the first layer's flour was very difficult. This may be due to the protein quality (much water-soluble protein), fiber, and damaged starch in this layer. Stability of the dough decreased gradually from the first to the fifth layer. The relatively high stability of dough from the first layer seems to be not real. These results coincide with the high weakening (260 B.U.) of the same layer's dough. The second layer was better in quality than the first or the third ones. It had less weakening and normal stability. The fifth (inner) layer has the lowest weakening (170 B.U.) but, at the same time, very low stability. Therefore, clear quality preperties of each layer are not defined by using the Farinograph.

Conclusions

Soaking wheat grains in water for a very short time helped in its bran removal by a special lab. rice mill. The ideal bran removal was obtained by soaking the grain of Giza 156 wheat variety for one minute, then tempering it for one minute and debranning it for 1-1/2 minute. For the Hurani durum wheat variety, tempering time was 2 minutes and debranning time 1 1/2 minutes.

Five successive layers were separated from the debranned grain by using the same laboratory rice mill. The outer layers were higher in protein content, especially in the Hurani grain. Also, lysine content was higher in the outer layers than in the

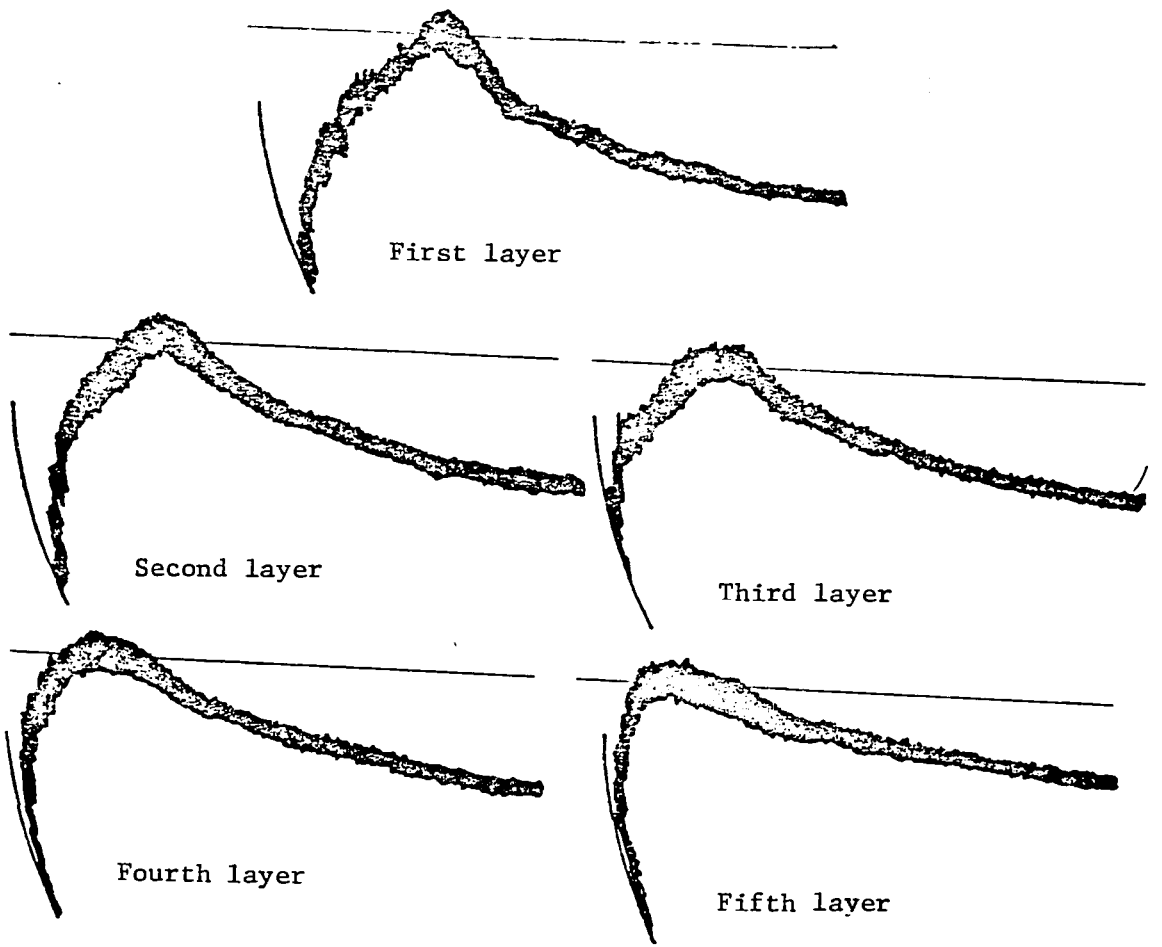


Fig. 1 -Farinograms of Giza 156 wheat kernel layers

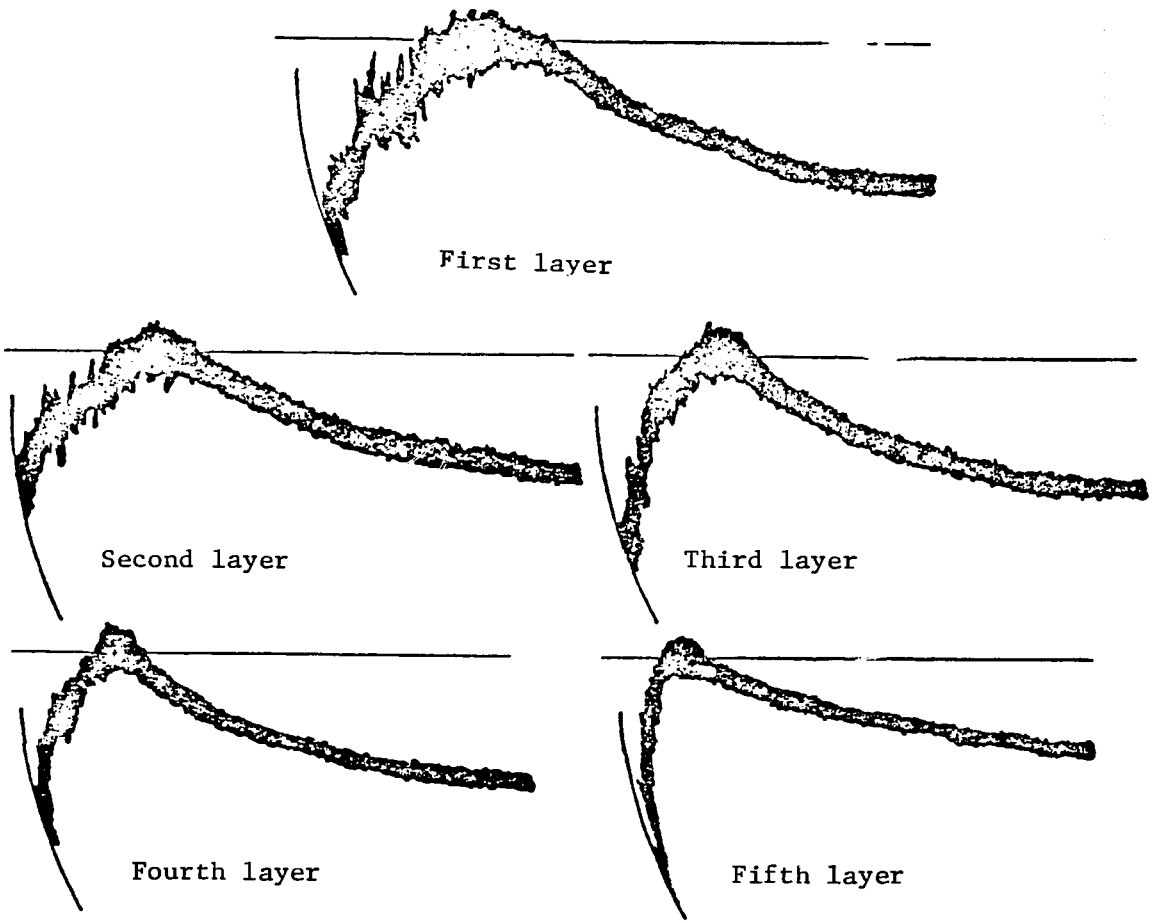


Fig. 2 -Farinograms of Hurani wheat kernel layers

outer layers than in the inner ones. The Farinograph test showed that the flour obtained from the inner layers of Giza 156 wheat grain was better in its stability and gluten strength than that of the outer layers of the debranned grain. For Hurani grain, the Farinograph was not suitable for testing the flour of the outer layers. It was difficult with such flour to form a stable dough. More improving time is needed to form the dough. The Farinograms of the inner layers were normal but the stability was very low and weakening was higher.

Literature Cited

American Association of Cereal Chemists.1969. Approved methods of the AACC Methods 30-10, 32-15, 44-16, 46-13, 54-21 and 76-20. The Association: St. Paul, MN

Copley, M.J., Ferrel, R.E. and Pence, J.W. 1966. Processing of wheat and products produced therefrom, U.S. Patent 3, 228, 771 Jan. II.

Pence, W.J., 1972. The students technology of bread making and flour confectionery. Printed by Lowe and Brydone (Printers) Ltd. London.

Winton, J.J.C. 1959. The distribution of ash in the wheat kernel. Cereal Chem. 36:19.

Kent Jones, D.W. and Amos, J.A. 1967. Modern cereal chemistry. The Northern Publishing Co. Liverpool 6th Ed.

Khorshid, A.M. 1976. Wet and dry debranning of wheat kernels and their effect on milling quality. Egypt J. Food Sci., 4, No. 1-2.

Orth, R.A. and Mander, K.C. 1975. Effect of milling yield on flour composition and bread making quality. Cereal Chem. 52:305.

Pomeranz, Y. 1971. Wheat chemistry and technology. Published by AACC St. Paul, Minnesota.

Stevens, D.J., McDermott, and Pace, J. 1963. Isolation of endosperm protein and aleurone cell contents from wheat, and determination of their amino acid composition. J. Sci Fd. Agric. 14:284.

Theodore, W., Robert E. Ferrel and James W. Pence 1970. Mechanical debranning of whole kernel wheat. I. Engellberg and McGill rice mills. Cereal Science Today 13 May.

Villegas, E. and Mertz, T.M. 1971. Chemical screening for maize protein quality at CIMMYT. Research bulletin No. 20, Mexico.

Waggle, D.H., Lambert, M.A., Miller, G.D., Farrell, E.P., and Deyoe, C.W. 1967. Extensive analysis of flours and mill feeds made from nine different wheat mixes. Amino acids, minerals, vitamins and gross energy. Cereal Chem. 44:48.

RECENT ADVANCES IN EVALUATION OF DURUM WHEAT QUALITY

J. S. Quick, R. A. Johnston,
V. S. Vasiljevic, and Y. Holm
United States

Abstract

New procedures such as the sedimentation test for gluten quality and comparison of methods for determining semolina color developed recently in the North Dakota breeding-quality program will be discussed.

The major quality objectives of durum wheat (*Triticum turgidum* L.) breeding programs throughout the world usually include high yellow colored semolina or flour, high gluten strength, high kernel vitreousness, large kernel size and weight, and freedom from kernel diseases which may impart specks to the semolina. These kernel characteristics produce a final pasta product with a bright yellow color, cooked firmness, tolerance to overcooking, and freedom from specks. The effective manipulation of these traits by breeding programs depends on the inheritance of the traits, their genetic variance, and the availability of efficient screening methods. Efficient screening methods require a small amount of grain, simple equipment, and must be rapid and repeatable. This paper describes recent findings on the genetic improvement of yellow endosperm color and gluten strength, two characteristics of great importance to the pasta industry and, until recently, more difficult to evaluate than other kernel traits.

Semolina Color

Previous studies have shown that yellow pigmentation is controlled by several genes whose action is mostly additive (3, 8). Genetic variation has been demonstrated by many breeding programs. Consequently, selection progress utilizing early generation evaluation, small sample sizes, and rapid analysis, should be effective. Three methods, visual, pigment extraction, and light reflectance, are available to evaluate semolina color. Visual evaluation is least desirable due to subjective bias and the potential problem of color change in the standard with time (16). The AACC approved method for measuring semolina color, using water saturated butanol, corrects the problem of precision but is relatively slow (1) and destroys the sample. More than 10 g of grain is required for accurate visual and pigment extraction methods, an amount much greater than produced by F_2 evaluation with dryland (rainfed) conditions; even using spaced plants (2 to 4/30 cm^2). Consequently, color reflectance using smaller seedlots and various instruments has become

Agricultural Experiment Station, North Dakota State University

the most desirable alternative. Konzak et al. (9) reported a micro-screening method for semolina color applicable to early generation material. They compared the effect of tempering (conditioning with water) on semolina yield and color from samples milled on two different micromills. A comparison of color scores obtained by visual rating and with a Neotec DU-COLOR meter allowed them to conclude that 1 to 2 g samples were too small for accurate reflectance scoring; however, scores from samples of 3 g or greater did compare favorably to visual scores.

Gluten Strength

Past studies have shown that gluten strength in durum wheat is controlled by more than one gene and that gene action is mostly additive (3, 11). Genetic variation has been demonstrated by several programs (4, 10, 13). Consequently, selection progress utilizing early generation evaluation, small sample sizes, and rapid analysis should be effective. Four types of tests utilizing relatively small sample sizes (less than 25 g of wheat) are available for gluten evaluation. They are the mixogram, gluten ball evaluation, viscoelastograph, and sedimentation. The mixogram technique as developed by Bendelow (2) is presently used in the Canadian and North Dakota programs and is effective only to distinguish large differences in gluten quality (10, 11). The test requires about 25 g of wheat and one person can evaluate about 25 samples of semolina per day. The gluten ball evaluation is used in Italy and by CIMMYT and others (Centro Internacional de Mejoramiento de Maiz y Trigo) (4). The test requires about 10 g of grain from which the gluten is washed to form a wet gluten ball which is placed on a glass sheet or hung from a pin. Gluten strength is estimated by the degree that the ball spreads or extends, respectively, in 30 minutes. The viscoelastograph test requires 10 to 20 g of wheat which is milled and purified followed by dough kneading, cutting into disks, drying, cooking, and compressing. The test accurately determines swelling, compressibility, and recovery of a cooked disk, but is time consuming, utilizes complex equipment, and requires a minimum of 10 g of wheat. A new wholemeal sedimentation test using a sodium dodecyl sulfate (SDS)/lactic acid solution (12) was recently developed to evaluate breadmaking quality. This test requires 6 g or less of wheat, uses simple equipment, and one person can evaluate 120 samples per day. We have recently evaluated the relationship between the wholemeal sedimentation and the mixogram tests for gluten strength prediction. An additional objective of recent experiments has been to evaluate the sedimentation test for use with semolina and reground semolina to obtain color and gluten tests on the same sample.

Materials and Methods

Color Evaluation

Ten durum wheat cultivars representing a range in semolina color and grown under typical North Dakota conditions in 1976 were evaluated to compare the sensitivity of the reflectance method as

affected by sample size (Table 1). A bulk lot of each cultivar was subdivided into sample sizes of 1, 2, 20, and 200 g and four replications (one per day) were milled and evaluated. The 20 and 200 g samples were tempered to 14.5% moisture approximately 18 hr before milling on a Brabender Quadramat Jr. mill with semolina purifier attached as described by Vasiljevic et al. (15). The 1 and 2 g samples were milled in a UDY cyclotec mill with a 500μ screen attached. Shortly after milling the four sample sizes, the samples were tested for yellow color on the Gardner Digital Color Difference Meter model XL-10 by measuring only the degree of yellowness obtained from the "b" scale. The standard glass bottom sample cup used for the 20 and 200 g samples was modified for the 1 and 2 g samples by adding to the bottom of the cup a black cardboard case with a central disc 25 mm in diameter removed.

Ten additional durum cultivars were grown at Langdon, ND, in 1978 to compare the three color evaluation methods, reflectance, free lutein pigment content, and carotene content (7). The reflectance and pigment evaluation methods each had been compared previously with visual scores but had not been directly compared. The semolina preparation and reflectance methods were the same as above. Pigment extraction was with the AACC water saturated butanol (WSB) method (1) except that the extraction time was 18 hours (normal is 16).

Table 1. Color expression of durum cultivars used for evaluation of semolina color methods.

Cultivar	b value (200 g)	Yellow color expression
Macoun	20.5	high
Quilafen	20.0	high
Ward	19.7	high
Calvin	19.6	high
Gediz	19.2	medium
Cando	18.3	medium
Mexicali 75	18.0	medium
Cocorit 'S'	16.5	low
Anhinga 'S'	15.8	low
Cocorit 71	14.7	low

Gluten Evaluation

Four experiments were conducted to compare the sedimentation and mixogram tests. Experiment I compared 25 F_3 lines from a cross between strong and weak gluten parents grown at Langdon, ND in 1977 (14). Experiment II compared wholemeal samples from 16 cultivars and experimental lines grown at four locations in North Dakota in

1979. The 6 g wheat samples in experiments I and II were milled to wholemeal using a UDY mill with a 1.0 mm sieve 24 hours before the sedimentation test.

In experiment III semolina samples from 16 cultivars and lines grown at Langdon and Minot in 1979 were evaluated. Two types of semolina were used, one produced by milling the wheat on a Brabender Quadramat Jr. mill with semolina purifier attached as described by Vasiljevic et al. (15), and the second by milling on a Buhler experimental mill specially designed for milling durum wheat. The mill is equipped with corrugated rolls throughout and the semolina purified on a Miag laboratory purifier. The wheat was tempered in three stages: first to 12.5% moisture 72 hours prior to the second stage, second to 14.5% moisture for 24 hours, and third to 17.5% moisture 45 min. prior to milling. The purified semolina was used in the quality tests. In experiment IV the semolina samples from the same 16 cultivars and lines used in experiment III, but grown at Dickinson and Fargo in 1979 and milled on the modified Brabender, Jr. and the Buhler mills were ground again (reground) using a UDY mill with a 1.0 mm sieve 24 hours before the sedimentation test.

Mixogram evaluation of the materials from the four experiments was done as part of the routine quality evaluation program. Micromixograms were obtained on a micromixograph (National Mfg. Co., Lincoln, NE) using 10 g of semolina, 5.8 ml of distilled water, and a spring setting of 8. Curves were scored from 1 to 8 with increasing numerical value indicating stronger gluten (Figure 1). SDS-sedimentation volumes were determined on remnant seed samples for each experiment.

The wholemeal samples in experiment I were suspended in 50 ml of water by rapid shaking for 15 sec in 100 ml stoppered measuring cylinders and similarly hand shaken at 2 and 4 min. Fifty milliliters of 2% sodium dodecyl sulfate and 1 ml of 85% lactic acid: water (1:8 v/v) were added and the contents of the cylinders mixed by inverting four times. The cylinders were similarly inverted at 2, 4, and 6 min. The contents were allowed to settle and sediment volumes recorded at 5, 10, 15, and 20 min. The procedure used in experiment I was modified for experiments II, III, and IV by using a continuous laboratory inverter following addition of the SDS and lactic acid solutions, and by recording the sediment volume only after 10 min. Examples of wholemeal sediment volumes after 10 min using weak (Rugby) and strong (Edmore) gluten durum cultivars are shown in Figure 2.

Protein contents of the grain samples were determined by the standard AACC Kjeldahl method (1) and expressed on an "as is" moisture basis (about 12%) after storage in paper packets for 2 to 6 months after harvest. Cooked spaghetti firmness for experiments II, III, and IV was determined by method of Walsh (17).

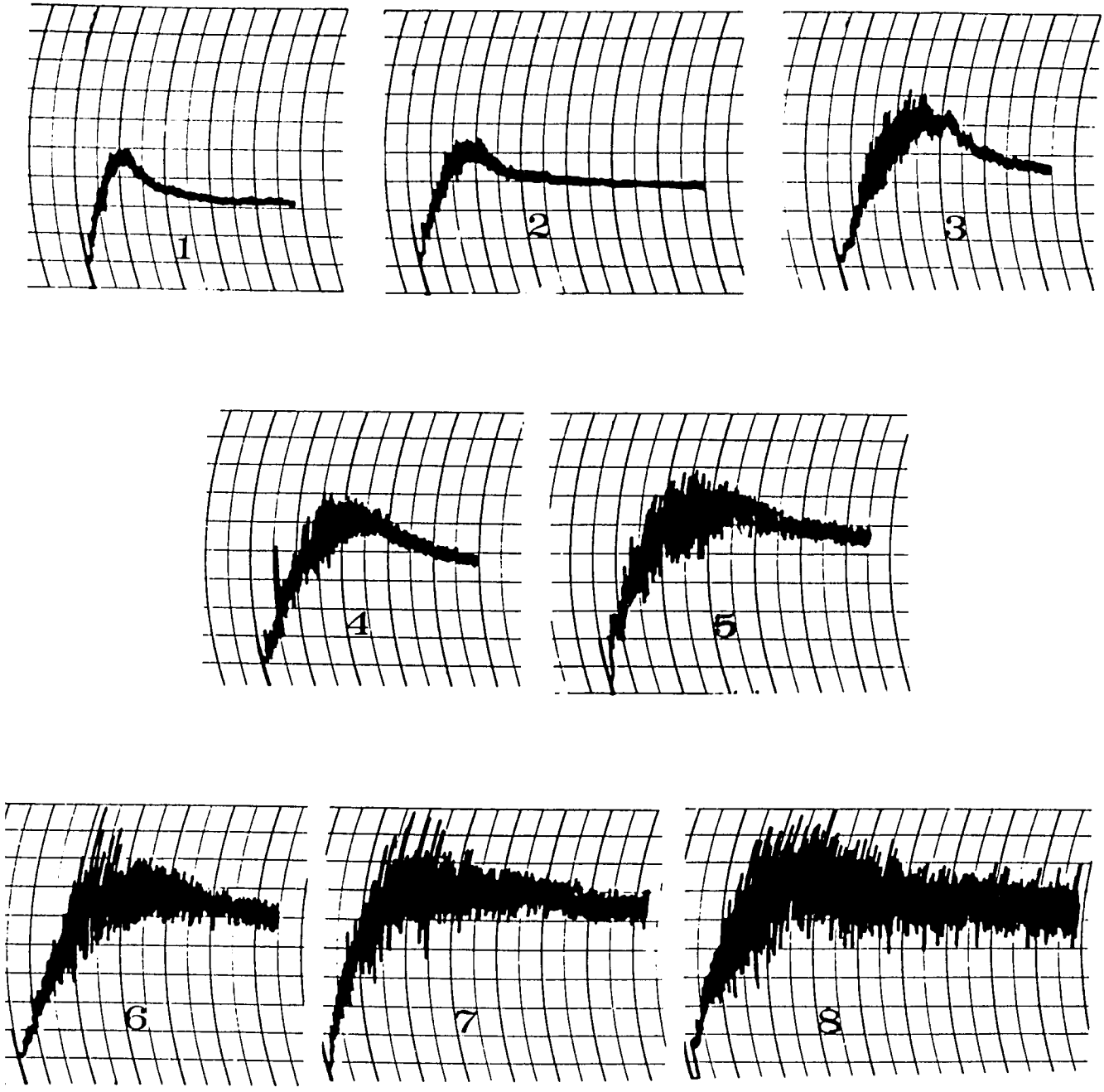


Figure 1. Reference mixograms for durum wheat, North Dakota State University, Agricultural Experiment Station, Department of Cereal Chemistry and Technology.

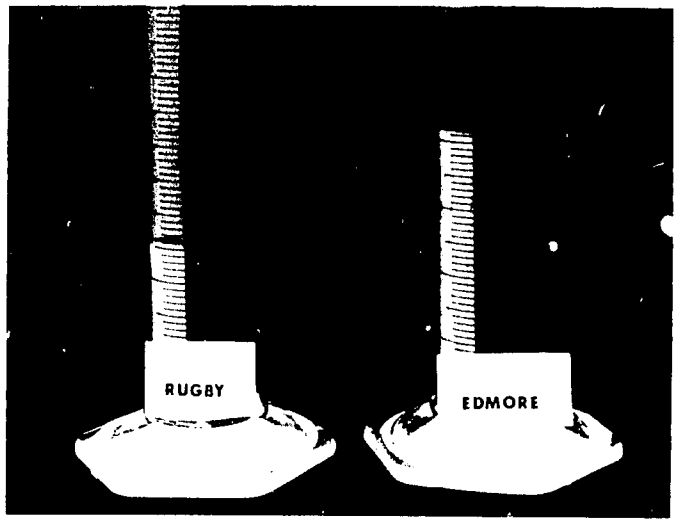


Figure 2. Sediment volumes after 10 min using weak (Rugby) and strong (Edmore) gluten durum cultivars.

Results and Discussion

Color Evaluation

Detailed results and discussion of the color tests were given by Johnston et al. (7, 8). The correlation coefficients for color scores among the sample sizes ranged from 0.85 to 0.93. The 200 g sample size was the most sensitive and repeatable test based on color range and standard deviation, and was recommended for evaluating advanced material (Table 2). The 20 g sample size was recommended for the best use of time while retaining sensitivity. The 1 and 2 g sample size was adequate for separating the high color from the low in a segregating population where sample size is limiting. The recommendations were made with the assumption that little or no lipoxygenase activity occurs in the lines tested, as the predictive value of semolina color for spaghetti color is altered greatly by the action of this enzyme (6).

Table 2. Mean, range, and standard deviation (SD) for four sample sizes.

Sample size (g)	"b" yellow value		
	Mean	Range	SD
200	18.3	5.6	1.8
20	17.9	5.1	1.7
2	13.7	2.2	0.7
1	13.7	2.2	0.7

The lutein pigment content and carotene content were highly associated with reflectance "b" value (r = 0.85 and 0.83, respectively). Since the reflectance method is much quicker, it should be the method chosen for both early generation testing with small sample size and for final color evaluation.

Gluten Evaluation

Detailed results of experiment I were presented by Quick and Donnelly (14). They found that correlation coefficients between sediment volumes and mixogram scores were positive and highly significant, and that the coefficients of determination (r^2) indicated that about 65% of the variation in mixogram score was attributed to its association with sediment volume. The correlations between sediment volumes at various settling times were all near 1.0, indicating that a reduced time period could be used. The correlations

between protein content and sediment volumes or mixogram scores were near zero, although the protein range was relatively narrow (15.1-17.2%). Using a simulated selection situation, they showed that the sedimentation test correctly predicted 21 out of 25 strong gluten samples (84%), an acceptable success level in the early generation evaluation program.

Means, ranges, and correlations for 16 cultivars and lines grown at four locations in 1979 and compared in experiment II are shown in Tables 3 and 4. Among the six correlations, all but protein content vs sedimentation volume were positive and highly significant. The r^2 values for the association between protein content and mixogram and sedimentation were both below 0.10, indicating that little variation in either gluten test was attributed to association with protein content.

In experiment II protein content had a much higher association with firmness, the trait that the gluten tests were designed to predict. The range of protein content was much greater than in experiment I, probably resulting in higher correlations. The correlations between firmness and the two gluten tests were the same, and the correlation between the mixogram and wholemeal sedimentation was similar to experiment I. The high associations between mixogram and sedimentation agree with those of Dexter et al. (5) comparing mixogram and wholemeal sedimentation procedures.

The means, ranges, and correlations for seomlina sedimentation tests (experiments III and IV) are shown in Tables 3 and 5. The wheat protein, spaghetti firmness, mixogram score, and wholemeal sedimentation means and ranges were similar for the two experiments. Using the same locations to evaluate all entries would have been desirable, but seed quantity was limited; however, since the means and variances were similar, little precision apparently was lost. The means and variances indicate that the use of semolina for sedimentation tests reduced the sediment volume. The Buhler mill generally produces semolina with a larger uniform particle size than the Quadramat, Jr., and since sedimentation volume probably is affected by particle size, the volume using Buhler semolina was lower. When the two sources of semolina were reground, the sedimentation values were nearly equal to the mean and range of wholemeal samples. The high association between wholemeal sedimentation volume and reground semolina sedimentation volumes are indicated by correlation values of 0.96 and 0.94. The correlation coefficients between wholemeal and semolina sedimentation volumes also were highly significant and therefore semolina could be used to determine gluten strength if the differences among samples were great and a UDY or similar mill was not available.

Table 3. Means and ranges for four traits measured in Experiments II, III, and IV.

Trait	Experiment II (n = 64)		Experiment III (n = 32)		Experiment IV (n = 32)	
	Mean	Range	Mean	Range	Mean	Range
Wheat protein	13.9	10.7-16.1	14.3	11.6-15.9	13.5	10.7-16.1
Spaghetti firmness	5.6	3.3-8.0	6.0	4.5-7.6	5.3	3.3-8.0
Mixogram score	4.3	2-8	4.2	2-8	4.4	2-8
Sedimentation volume:						
Wholemeal	41.4	24-63	44.0	27-61	38.9	24-63
Quadramat, Jr.			22.8	18-33	35.3	18-60
Buhler			17.8	14-22	31.6	17-57

Experiment II = four locations; Experiment III = Langdon and Minot with semolina; and Experiment IV = Dickinson and Fargo with reground semolina.

Table 4. Correlation coefficients among wheat protein, spaghetti firmness, mixogram, and wholemeal sedimentation for 16 durum wheat cultivars and lines grown at four North Dakota locations in 1979.

Comparisons	Coefficients
Firmness vs protein content	0.65**
Firmness vs mixogram	0.70**
Firmness vs sedimentation	0.70**
Protein content vs mixogram	0.30**
Protein content vs sedimentation	0.21
Mixogram vs sedimentation	0.80**

**Significant at the 0.01 level.

Table 5. Correlation coefficients among sedimentation volumes obtained from wholemeal, two semolina sources, and two reground semolina sources (n = 32).

Comparisons†	Coefficients
Wholemeal vs Q semolina	0.71**
Wholemeal vs B semolina	0.70**
Wholemeal vs Re-Q semolina	0.96**
Wholemeal vs Re-B semolina	0.94**
Q semolina vs B semolina	0.81**
Re-Q semolina vs Re-B semolina	0.94**

†Q = Quadramat, Jr.; B = Buhler; and Re- = UDY reground semolina.
**Significant at the 0.01 level.

Conclusions

The results of these experiments indicate that both color and gluten testing is effective on small samples (less than 10 g) using simple equipment in rapid and repeatable tests. The color reflectance method and the SDS-sedimentation method allow evaluation of seed from single plants as early as the F_2 generation. Since the semolina or wholemeal flour produced for the color reflectance test is not physically or chemically altered, the same sample can be utilized for the sedimentation test. If semolina is produced for a more precise color determination, it can be reground to a flour in a UDY or similar mill to produce results very similar to wholemeal samples. Thus, at least 100 samples/day/person could be milled and tested for both color and gluten strength allowing more rapid progress in breeding improved cultivars.

References

1. American Association of Cereal Chemists. 1962. Cereal laboratory methods. The Association: St. Paul, MN.

2. Bendelow, V. M. 1967. Early generation screening for gluten strength in durum wheat breeding. Cereal Sci. Today 12:336-337.

3. Braaten, M. O., K. L. Lebsock, and L. D. Sibbitt. 1962. Intergeneration relations of physical properties of dough and carotenoid pigment content in durum wheat. Crop Sci. 2:277-281.

4. Centro Internacional de Mejoramiento de Maiz y Trigo. 1977. CIMMYT Review. El Batan, Mexico, p. 59.

5. Dexter, J. E., R. R. Matsuo, F. G. Kosmolak, D. Leisle, and B. A. Marchylo. 1980. The suitability of the SDS-sedimentation test for assessing gluten strength in durum wheat. Can. J. Plant Sci. 60:25-29.

6. Irvine, G. N., and J. A. Anderson. 1953. Variation in principal quality factors of durum wheats with a quality prediction test for wheat or semolina. Cereal Chem. 30:334-342.

7. Johnston, R. A. 1980. Semolina color and other quality and agronomic traits in durum: genetics and methods. Ph.D. Thesis. North Dakota State University, Fargo, ND.

8. Johnston, R. A., J. J. Hammond, and J. S. Quick. 1978. Gene effects for semolina color in six durum wheat crosses. Agron. Abst. p. 54.

9. Konzak, C. F., R. Hu, G. L. Rubenthaler, M. Sadam, and W. C. Shuey. 1973. A rapid micro screening method for semolina color applicable to early generation materials. Proc. Symp. Genetics and Breeding of Durum Wheat, Bari, Italy. pp. 617-631.

10. Leisle, D., and R. J. Baker. 1973. An evaluation of quality testing in durum wheat. Proc. Symp. Genetics and Breeding of Durum Wheat, Bari, Italy. pp. 549-559.

11. Lukach, J. 1980. Gluten strength evaluation in durum wheat. M.S. Thesis. North Dakota State University, Fargo, ND.

12. McDermott, E. E. and D. G. Redman. 1977. Small-scale tests of breadmaking quality. FMBRA Bulletin, No. 6, pp. 200-213.

13. Quick, J. S., B. J. Donnelly, and J. D. Miller. 1979. Edmore... North Dakota's first strong gluten durum. N. D. Farm Res. 36(7): 14-18.

14. Quick, J. S. and B. J. Donnelly. 1980. A rapid test for estimating durum wheat gluten quality. Crop Sci. (in press)

15. Vasiljevic, S., O. J. Banasik, and W. C. Shuey. 1977. A micro unit for producing durum semolina. Cereal Chem. 54(3):397-404.

16. Walsh, D. E. 1970. Measurement of spaghetti color. Macaroni J. 52:20-22.

17. Walsh, D. E. 1971. Measuring spaghetti firmness. Cereal Sci. Today 16:202-205.

PROCESSING QUALITY OF HIGH PROTEIN WHEATS

P. J. Mattern, V. A. Johnson, and S. L. Kuhr
United States

Abstract

Two-hundred lines of high protein-high lysine progenies, including eight check varieties, were screened for their bread baking potential. Samples, equally divided between spring and winter types, were grown under irrigation at Yuma, Arizona during 1977, and were selected from the most productive and/or highest protein lines. Samples were micro milled and the flours were evaluated for their mixing characteristics with a ten gram mixograph.

Sixteen winter lines and fifteen spring lines were identified as possible bread baking types. Nine of the winter types and six of the spring wheats had acceptable hard milling quality.

Additional studies were carried out on twelve different high protein-high yielding wheat lines which were under consideration as possible candidates for the International Winter Wheat Performance Nursery. Four of these lines were adequate in mixing potential, and of these, two were hard milling (endosperm) types and two were soft milling types.

These processing data will be useful for breeders wishing to select superior high protein-high yielding lines with specific end quality uses.

The University of Nebraska initiated a project in 1966 to identify wheat germ plasm with improved protein nutritional quality. Identified materials have been incorporated into improved agronomic types and this paper contains data for milling and dough mixing properties.

This research has been a cooperative effort with the University of Nebraska, U.S. Department of Agriculture, SEA, AR, and U.S. International Development Corporation, Agency for International Development.

Materials and Methods

Samples

One-hundred winter lines and one-hundred spring wheat lines were selected from the advanced High Protein-High Lysine (HP-HL)

Department of Agronomy, University of Nebraska.

Observation Nursery grown at Yuma, Arizona in 1977. Selection of entries was based on best levels of grain protein and yield data.

Twelve entries and controls were selected from wheat harvested in 1979 at Yuma, Arizona for possible use as future candidate lines for the International Winter Wheat Performance Nursery (IWWPN).

Control samples did not necessarily follow the growth habit but were selected as a quality reference. Both winter and spring types were fall planted at Yuma, Arizona and were harvested at about the same time.

Milling

Thirty-five gram samples were tempered to a moisture content of 15%, milled with a C. W. Brabender Quadrumat Jr. Experimental Mill and sifted on an external sifter with a U.S. Standard Sieve No. 70 with 210 micron openings.

Protein

Kjeldahl nitrogen was determined in duplicate on one gram wheat samples following AACC method 46-12 (1). Protein was calculated using % N x 5.7. Data is reported on a dry weight basis.

Mixograms

Ten gram flour samples were evaluated at 62% absorption on a National Manufacturing Company micro mixograph (2).

Results and Discussion

High Protein-High Lysine Observation Nursery Samples Winter Types

Sixteen winter lines had satisfactory mixing characteristics when compared to the four controls Bezostaya, CI 13449, Centurk and Lancota (Figure 1). Irrigation under Yuma, Arizona conditions reduced mixing times of the control samples from what would be expected from dryland production in Nebraska. The sixteen lines selected had longer mixing times and higher protein levels than the controls (Figure 2).

Nine of the sixteen winter types selected for their mixing characteristics had hard milling properties as judged by bran clean-up and flour yield (Table 1). Yield data are provided for Yuma, Arizona, and an average for seven world sites. Comprehensive information on HP-HL samples from all world wide locations will be available in a separate future publication.

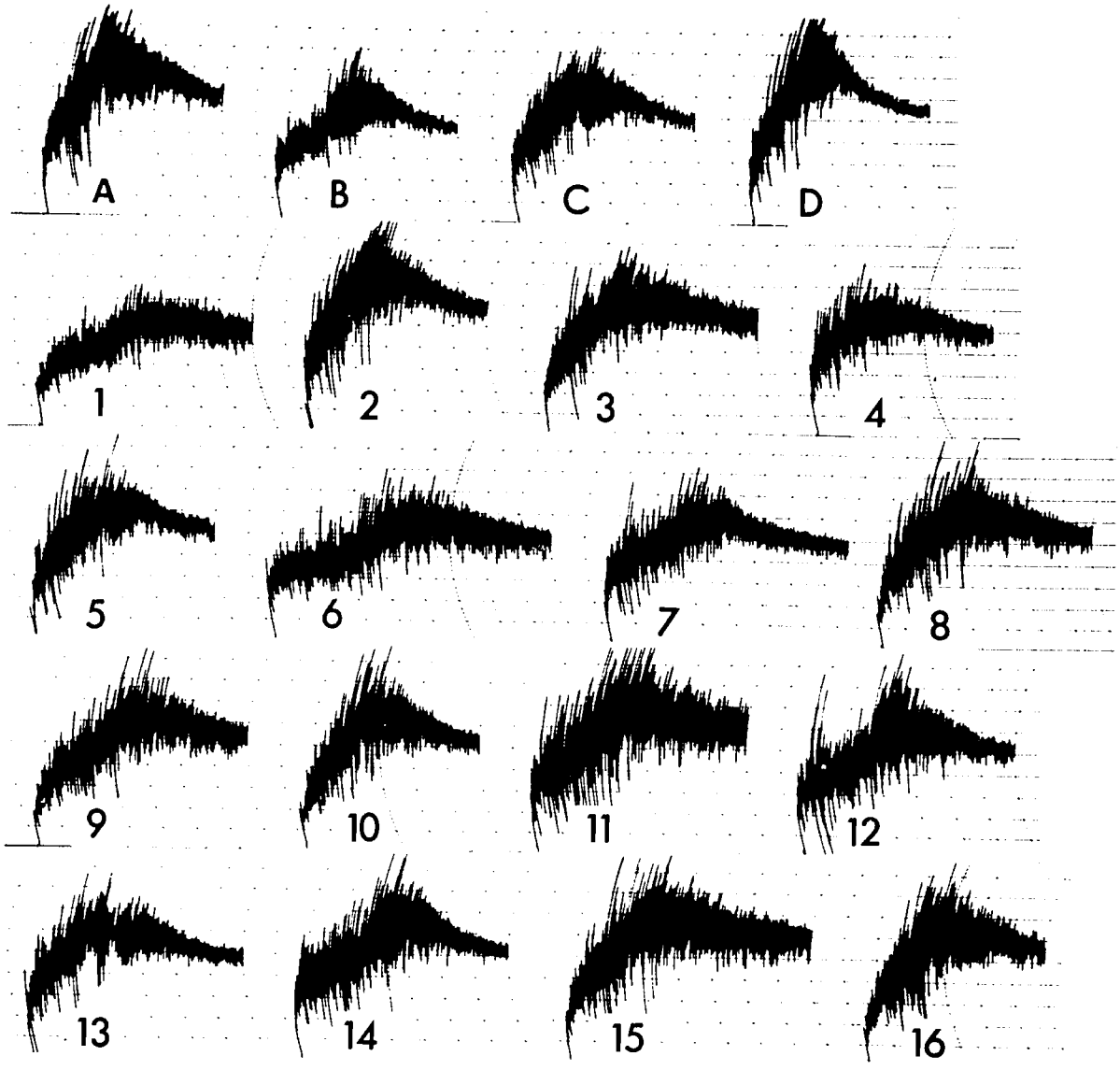


Figure 1. Mixing curves for High Protein-High Lysine Observation Nursery, winter selections, Yuma, Arizona, 1977. A, Bezostaya; B, CI 13449; C, Centurk; D, Lancota; 1, 77Y1010; 2, 77Y1013; 3, 77Y1029; 4, 77Y1037; 5, 77Y1049; 6, 77Y1050; 7, 77Y1055; 8, 77Y1084; 9, 77Y1086; 10, 77Y1087; 11, 77Y1091; 12, 77Y1112; 13, 77Y1127; 14, 77Y1140; 15, 77Y1150; 16, 77Y1157.

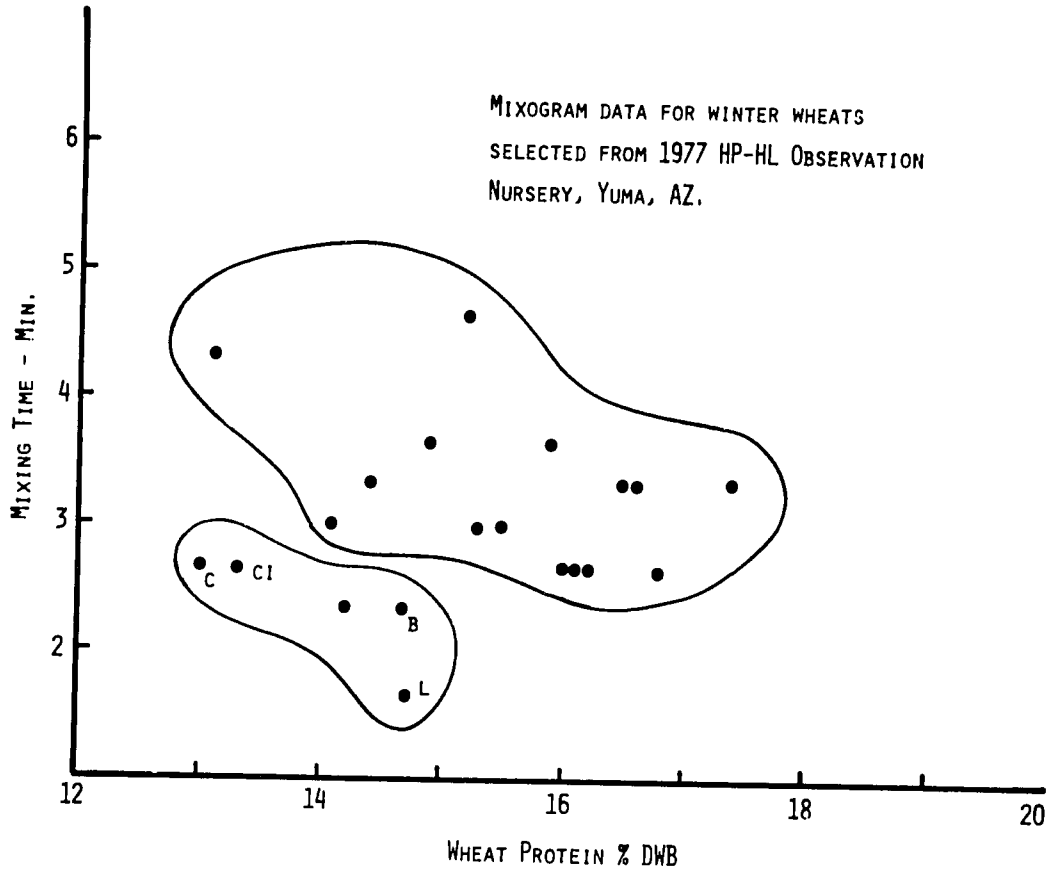


Figure 2. Mixogram data for winter wheats selected from 1977 HP-HL Observation Nursery, Yuma, Arizona. Letters identifying the controls are: B, Bezostaya; C, Centurk; CI, CI 13449; L, Lancota.

The agronomic characteristics of the original high protein-high lysine germ plasm was poor. These advanced lines represent improved yield and kernel types. This quality data will provide wheat breeders with a selection basis for processing and end use properties.

Spring Types

Fifteen spring lines had satisfactory mixing properties when compared to the Nap Hal, Atlas 66, INIA 66, and CI 13449 controls (Figure 3). The general level of quality of the spring selections was not equal to the winter materials because the crossing program has concentrated on winter types (Figure 4). However, the spring lines had excellent yield potential and protein levels under the Yuma, Arizona environment. Mixing types selected essentially approximated the INIA 66 control variety.

Table 1. High Protein-High Lysine Observation Nursery, winter selections, Yuma, Arizona, 1977.

Permanent no.	Yield 7 sites[1]	Yield Yuma	Wheat protein[2] Yuma	Milling[3] Yield	Milling[3] Type[4]	Mixogram Mix time
	q/ha		%			min.
Bezostaya	38.1	35.3	14.7	72.9	G	2 1/3
CI 13449	30.6	34.2	13.3	72.9	P	2 2/3
Centurk	46.9	50.4	13.0	67.1	G	2 2/3
Lancota	46.0	44.6	15.1	71.4	G	1 2/3
77Y1010	45.6	63.7	13.1	67.1	F	4 1/3
1013	42.1	46.6	14.2	70.0	G	2 1/3
1029	44.7	50.8	14.1	67.1	G-	3
1037	30.9	42.7	16.8	64.3	F	2 2/3
1049	32.5	47.4	16.1	67.1	G	2 2/3
1050	38.9	49.6	15.2	64.3	P	4 2/3
1055	34.9	42.9	16.2	63.4	F	3 2/3
1084	42.0	53.5	15.3	71.4	G	3
1086	47.0	59.6	14.9	67.1	G	3 2/3
1087	33.4	52.1	16.0	71.4	G	2 2/3
1091	35.1	35.5	16.5	65.7	G-	3 1/3
1112	41.2	55.7	14.4	62.9	P	3 1/3
1127	42.4	59.2	15.5	67.1	F	3
1140	33.3	45.0	17.4	66.3	F	3 1/3
1150	38.5	55.1	16.6	67.1	G	3 1/3
1157	33.7	39.7	16.2	67.2	G	2 2/3

1/ Karaj, Iran; Bethlehem, South Africa; Erzurum, Turkey; Bordenave, Argentina; Stillwater, Oklahoma; Yuma, Arizona; and Sulaimaniya, Iraq.

2/ Protein (N x 5.7), dry weight basis.

3/ Brabender Quadrumat, Jr.

4/ Poor, Fair, Good, based on bran clean-up.

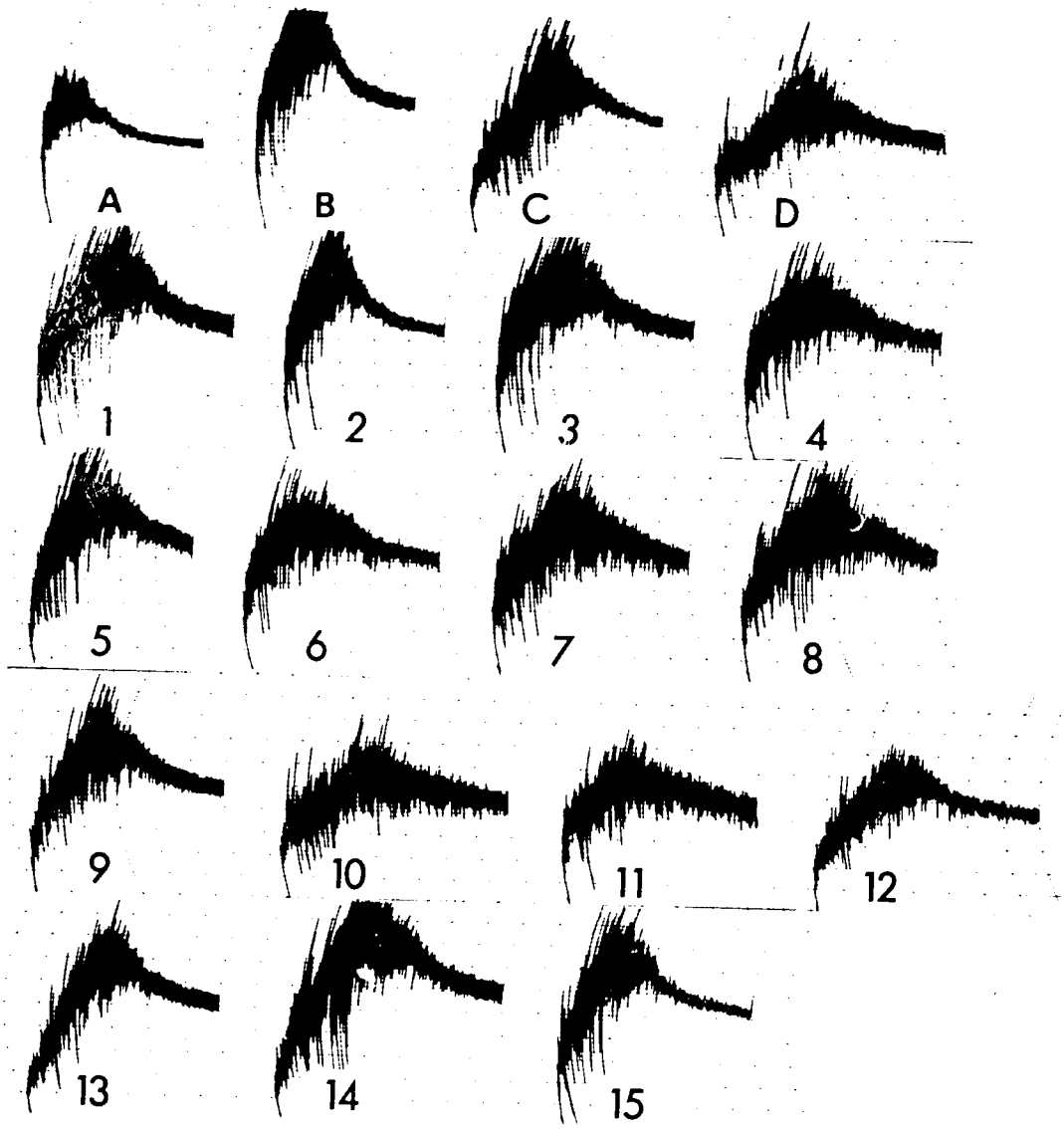


Figure 3. Mixing curves for High Protein-High Lysine Observation Nursery, spring selections, Yuma, Arizona, 1977. A, Nap Hal; B, Atlas 66; C, INIA 66; D, CI 13449; 1, 77Y1269; 2, 77Y1270; 3, 77Y1271; 4, 77Y1274; 5, 77Y1275; 6, 77Y1277; 7, 77Y1310; 8, 77Y1313; 9, 77Y1320; 10, 77Y1326; 11, 77Y1329; 12, 77Y1360; 13, 77Y1361; 14, 77Y1378; 15, 77Y1380.

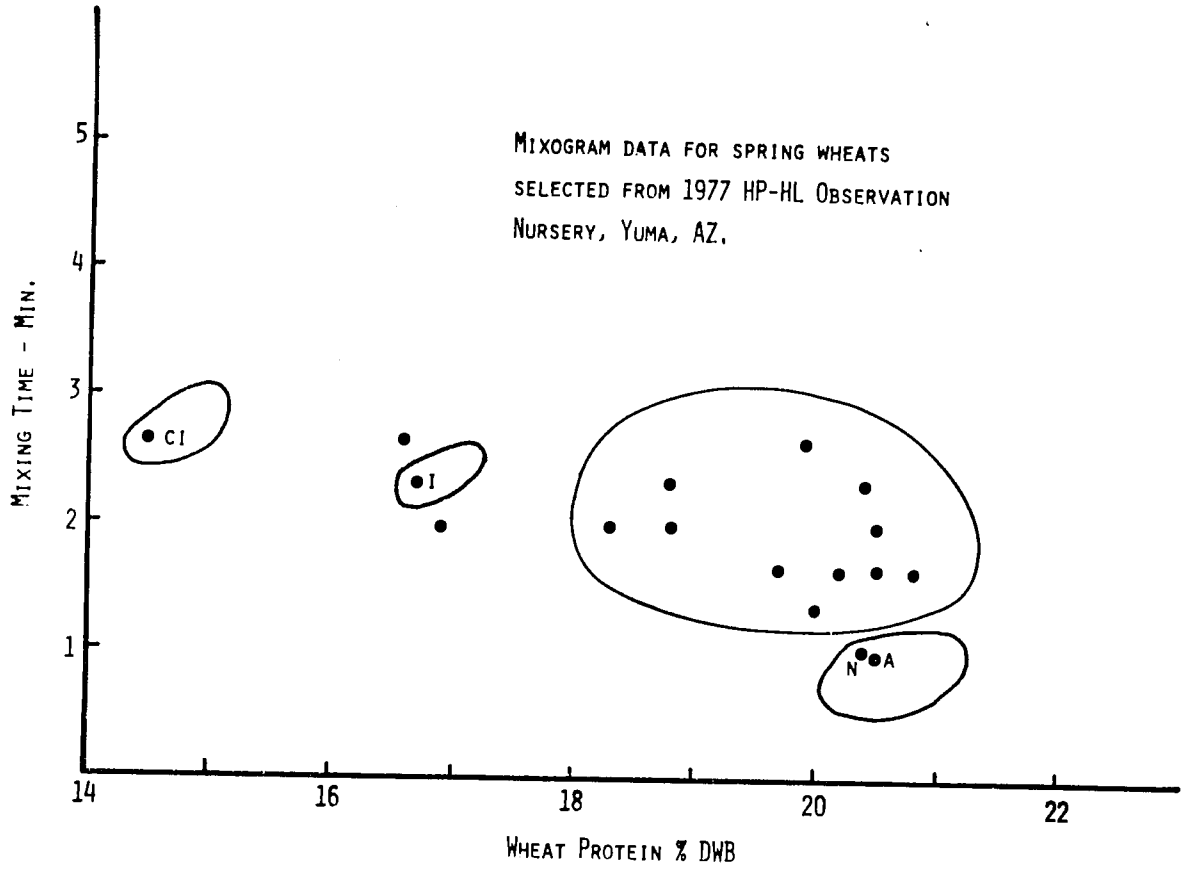


Figure 4. Mixogram data for spring wheats selected from 1977 HP-HL Observation Nursery, Yuma, Arizona. Letters identifying the controls are: A, Atlas 66; CI, CI 13449; I, INIA 66; N, Nap Hal.

Six of the fifteen lines identified had hard wheat milling properties as judged from flour yield and bran clean-up scores (Table 2).

Elite Observation Nursery

Promising agronomic material from advanced lines harvested in 1979 were tested in order to identify future IWWPN candidates with known processing quality.

Four of the twelve experimental lines had acceptable dough mixing properties (Figure 5), and mixing times were intermediate to the controls (Figure 6).

Table 2. High Protein-High Lysine Observation Nursery, spring selections, Yuma, Arizona, 1977.

Permanent no.	Yield q/ha	Wheat protein1/ %	Milling2/ Yield	Milling2/ Type3/	Mixogram Mix time min.
Nap Hal	24.8	20.4	61.4	P	1
Atlas 66	18.1	20.4	54.3	P	1
INIA 66	37.4	16.8	65.7	G	2 1/3
CI 13449	39.6	14.5	57.1	P	2 2/3
77Y1269	31.0	20.4	58.6	P	2 1/3
1270	36.2	20.5	58.6	P	1
1271	34.4	20.5	58.6	P	1 2/3
1274	36.9	20.2	60.0	P	1 2/3
1275	30.3	20.8	68.6	G	1 2/3
1277	33.4	20.5	58.6	P	2
1310	40.1	18.8	60.0	P	2
1313	36.2	20.0	60.0	F	2 1/3
1320	40.5	18.3	70.0	G	2
1326	40.9	16.6	62.9	P	2 2/3
1329	51.6	16.9	58.6	P	2
1360	59.9	16.5	65.7	G	2 2/3
1361	45.7	18.8	65.7	G	2 1/3
1378	25.0	18.9	64.3	G	2 2/3
1380	31.6	19.7	65.7	G	1 2/3

1/ Protein (N x 5.7), dry weight basis.

2/ Brabender Quadrumat, Jr.

3/ Poor, Fair, Good, based on bran clean-up,

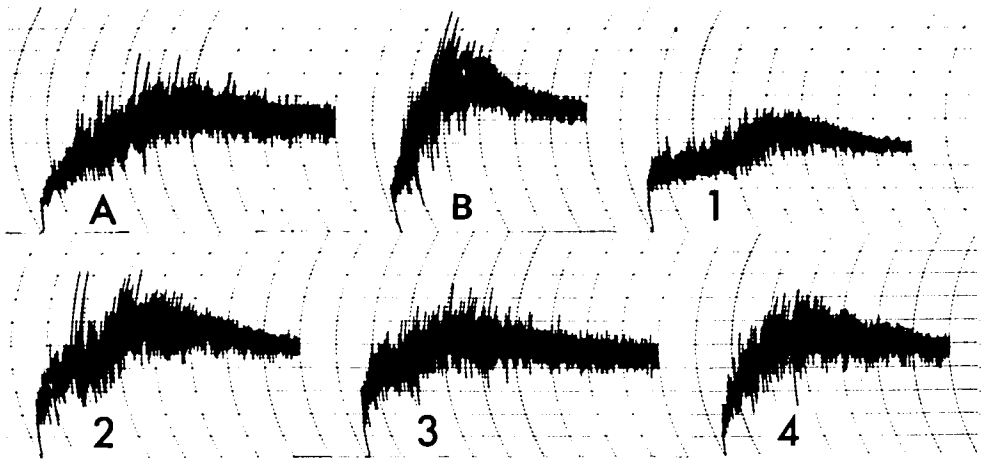


Figure 5. Mixing curves for IWWPN candidate varieties, winter selections, Yuma, Arizona, 1979. A, Centurk 78; B, Lancota; 1, 90576; 2, 90537; 3, 95097; 4, 90444.

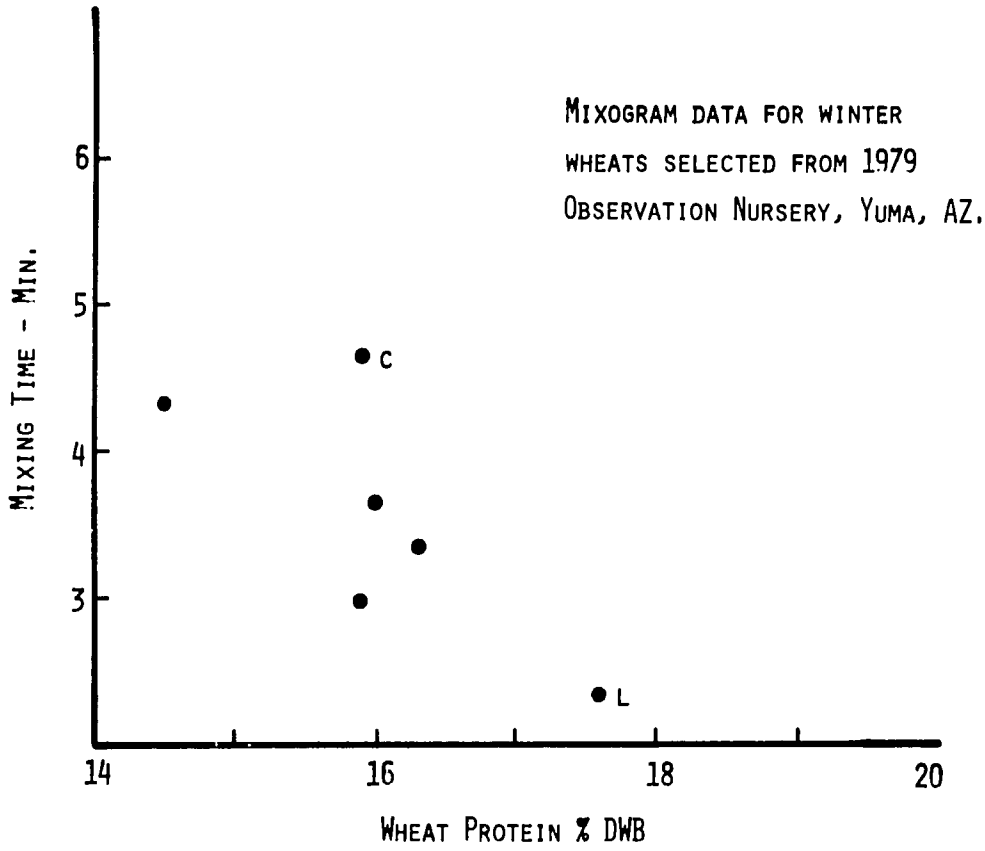


Figure 6. Mixogram data for winter wheats selected from IWWPN candidate varieties, Yuma, Arizona, 1979. Letters identifying the controls are: C, Centurk 78; L, Lancota.

Only two lines possessed satisfactory hard milling characteristics (Table 3). Grain yields of the experimentals were higher than the controls and this tended to equalize protein levels.

Table 3. 1979 candidate varieties for possible use in IWWPN, Yuma, Arizona, winter selections.

Permanent no.	Yield1/	Protein2/		Milling3/		Mixogram
		Wheat	Flour	Yield	Type4/	Mix time
	q/ha					min.
Centurk 78	45.3	15.9	14.4	64.2	G	4 2/3
Lancota	38.7	17.6	16.7	62.0	G	2 1/3
90576	65.0	14.5	12.6	65.1	F	4 1/3
90537	56.4	16.0	14.9	66.2	G	3 2/3
95097	59.3	16.3	14.2	61.1	P	3 1/3
90444	59.4	15.9	14.3	67.7	G	3

1/ $\bar{x}$ of 2 reps except Centurk 78, $\bar{x}$ of 3 reps.
2/ DWB; 3/ Brabender Quadrumat, Jr.; 4/ Poor, Fair, Good.

Conclusions

Progenies selected and tested in this study came from crosses which had been made to obtain the best combination of protein, lysine and grain yield. There had been no selection pressure for any kind of processing quality. Fortunately, wheat lines were identified which were hard endosperm types along with adequate dough mixing properties which should make them useful for bread production.

Due to losses of two consecutive nurseries in 1978 and 1979 there was no opportunity to complete the more definitive baking test. Baking should be completed during 1980.

Emphasis has been placed on the identification of wheats for bread production. However, information on soft wheat materials can be valuable for a soft wheat breeding program. Our continuing effort will be to characterize quality factors of improved nutritional wheats for as many end uses as possible.

Literature Cited

1. Approved Methods of the American Association of Cereal Chemists. American Association of Cereal Chemists, Inc., St. Paul, MN 55104, USA.

2. Finney, K. F. and Shogren, M. D. A ten-gram mixograph for determining and predicting functional properties of wheat flours. Bakers Digest 46(2):32-35, 38-42, 77 (1972).

PARAMETERS TO WHEAT QUALITY IMPROVEMENT IN A HIGH-YIELD SITUATION

E. J. Gallagher
Ireland

Abstract

Various aspects of wheat quality, viz. yield of flour, flour color, protein content, alpha-amylase levels, dough quality, can influence the utility of the wheat for milling and baking. The most critical criterion is the standard of loaf produced.

The optimization of husbandry inputs is essential when high yields of wheat are the norm. Data from Irish trials show that production inputs varied in their determining effect on wheat quality. Within a certain range variation in seeding rate had little effect on wheat quality. Time of sowing had an effect on quality, in an indirect manner. Increased nitrogen fertilization, in conditions where soil organic matter levels were relatively high, have had little effect on, or even disimproved wheat quality. The level of fungal disease control significantly influenced quality. However, in all situations cultivar was the most significant factor in determining wheat quality.

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As Ireland is an island, it would be desirable that it be self-sufficient in provision of wheat for breadmaking. The total grist requirement is approximately 300,000 m.t. per annum. The country has ample capacity to produce this quantity of grain. However, various quality characteristics limit the quantity of native wheat which can be used in the grist. A wheat research programme at University College, Dublin has examined the effect of production factors on the quality characteristics. Data from these trials are presented to illustrate the limitations to quality improvement.

Quality Evaluation.-- Numerous qualitative tests are available to classify wheat and wheat products. These tests have been used to ascertain and maintain milling and baking standards. In a research programme a judicous mix of tests enables an evaluation to be carried out on the effect of field treatments on eventual milling and breadmaking quality.

In the current programme the following tests were amongst those used:

Flour Extraction.-- Extractions were carried out on a Buhler mill which simulates commercial mill flour extraction and which would be expected to show up differences between wheats of different milling quality (McCluggage et al.). A standard mill

University College Dublin, Newcastle

setting was used throughout the milling process. Consequently, variations in extraction are a function of the wheat sample being milled.

Flour Color.-- Flour color is basically a function of the percentage of flour extracted. As extraction increases flour color will disimprove. However, other factors such as granulation, bran pigmentation, foreign material, etc. can influence flour color. Flour color determinations were carried out on a Kent-Jones and Martin flour color grader (Kent-Jones and Martin).

Enzyme Activity.-- In a situation where a high level of native wheat is included in the grist the level of alpha-amylase present is important. In Ireland, late and wet harvests can lead to premature germination or sprouting. When this sprouting is incipient it is difficult to detect visually. A test based on the physical characteristics of a heated ground-wheat water mixture (Hagberg) enables a rapid determination to be made of the level of alpha-amylase in wheat. An arbitrary critical value of 160 has been taken as the break-off point for acceptability. Wheat samples which have a Hagberg falling number value above 160 are considered to have an acceptable level of alpha-amylase activity. Below 160 alpha-amylase levels are deemed to be too high.

Protein.-- The percentage protein in wheat is the most universally accepted criterion of the suitability of a wheat for breadmaking. Wheat proteins in Ireland tend to be low and can often be a critical factor in determining the suitability of a wheat for breadmaking. Standard Kjeldahl procedure was followed in determining protein.

Dough Quality.-- The 'strength' of a wheat or flour is difficult to define. In a broad sense, flour which produced a resilient dough which bakes into a well-volumed loaf of good texture is considered to be a 'strong' flour. Many different types of apparatus have been developed to evaluate this characteristic. In this trial use was made of the Brabender extensograph and data are given for the area of curve, recorded on paper, which is produced when a dough is stretched. High values are generally indicative of good dough quality.

Baking Characteristics.-- In this trial series a pan loaf was baked with 400 g. flour, 8 g. sugar, 8 g. salt, 8 g. yeast. The loaf was examined under each of the following headings: (i) External appearance; (ii) volume; (iii) texture; (iv) crumb.

A loaf could obtain a maximum of 10 points under each of these headings. The total points actually obtained by each loaf was expressed as a percentage of the total points it could have obtained.

Effect of Production Factors on Yield and Quality

Seeding Rate.-- Within a certain range, variation in seeding rate had little effect on wheat quality. Standard seeding rate for spring wheat has traditionally been 190 kg/ha. Experimental data accumulated over a number of years would indicate that this is too low to achieve optimum yield as indicated in Table 1. In spite of the increase in yield obtained with increasing seeding rate, quality characteristics showed little or no change.

Table 1. Effect of seeding rate on yield and quality of spring wheat.

Seeding Rate kg/ha	Yield %	Flour Extraction %	Flour Color	Hagberg Falling Number	Protein %	Extensogram Area	Loaf Score %
140	100	61	5.0	202	10.6	68	57
188	107	60	4.7	204	10.8	72	58
235	113	62	4.8	205	10.7	67	54

Time of Sowing.-- Time of sowing had an effect on quality in an indirect fashion. The yield of spring wheat was decreased by differential sowing in the period from mid-March to the end of April (Table 2). Quality characteristics varied in their reaction to time of sowing.

The level of flour extraction disimproved, as yield decreased and grain became shriveled. Flour color became darker with delayed maturity leading to an increase of *Cladosporia* and *Alternaria* spp. on the grain. The Hagberg falling number became lower, again showing the effect of delayed harvest on grain sprouting and alpha-amylase levels.

Some quality characteristics improved. Grain protein increased in the later-sown wheat but this effect was rather misleading since the carbohydrate-nitrogen ratio disimproved in the later-sown wheat resulting in an overall increase in the percentage of protein in the grain but an actual decrease in the yield of protein per unit area. There was also an improvement in dough quality as reflected in the extensogram area and the overall effect was that late sowing led to an improvement in the bread produced.

Table 2. Effect of time of sowing on yield and quality of spring wheat.

Time of Sowing	Yield %	Flour Extraction %	Flour Color	Hagberg Falling Number	Protein %	Extensogram Area	Loaf Score %
Mid-March	100	63	4.0	228	10.0	63	51
Early April	95	62	4.7	205	10.7	67	57
End of April	73	60	5.7	176	11.1	77	61

Nitrogen Fertilization.-- Crop rotations in Ireland tend to have long runs of grass in them and consequently, soil organic matter is relatively high. In this situation, once the critical nitrogen requirement of the crop is supplied, further nitrogen fertilization has little effect on yield. In some cases yield is actually decreased due to increased vegetative growth and an increase in fungal disease levels.

Cereal quality also responds to nitrogen fertilization but there is a divergence in the response of various characteristics. In the trial series presented in Table 3, flour color was disimproved by increased nitrogen, partly due to an increase in the sooty moulds on the grain and partly due to a deterioration in seed coat color brought about by delayed maturity. There is also some evidence that alpha-amylase levels increase due to later maturation. Protein levels increase, particularly with the first increment of nitrogen, and this improvement is reflected to a lesser extent in bread quality.

Table 3. Effect of nitrogen fertilization on yield and quality of spring wheat.

Nitrogen Fertilization kg/ha	Yield kg/ha	Flour Extraction %	Flour Color	Hagberg Falling Number	Protein %	Extensogram Area	Loaf Score %
34	4880	67	3.5	203	10.0	51	45
85	5180	67	3.7	200	10.6	57	59
137	5030	67	4.4	189	11.4	57	66
188	5005	67	4.4	192	11.9	60	69

Fungicide Use.-- Under Irish conditions, where precipitation levels and humidity are relatively high, fungal diseases may reduce yield and, at times, disimprove quality. The main diseases generally of consequence in wheat production are powdery mildew (*Erysiphe graminis*) and *Septoria nodorum*. Yield depression from these diseases may result in shriveled grain; in the extreme situation this leads to reduced flour yields. In some circumstances shriveled grains, which have matured prematurely, germinate in the ear prior to harvest. In extreme cases shriveling results in increased protein levels as the carbohydrate-nitrogen ratio in the grain decreases.

Data from a fungicide trial are presented in Table 4. Cultivars, in a split-plot arrangement, were treated with either a single or multiple-spray application of a broad-spectrum fungicide. There was a significant increase in yield, in many instances, from increased fungicide use. A pronounced cosmetic effect was obtained with increased fungicide use and this resulted in a maintenance of leaf area duration and consequent later maturity. This may have resulted in the noticeable increase in alpha-amylase activity in certain cultivars. It can only be speculated that the increase in protein content was due to the maintenance of the plant transportation system brought about by the reduction of disease levels.

Table 4. Effect of fungicide on yield and quality of spring wheat.

Cultivar	Yield kg/ha		Flour Extraction %		Flour Color		Hagberg Falling Number		Protein %		Extensogram Area		Loaf Score %	
	F_1 *	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Sappo	6249	7089	72	72	3.2	3.2	216	231	11.9	12.4	145	138	74	85
Sicco	7781	8349	75	73	2.0	1.7	304	290	11.9	12.1	167	134	82	73
Kleiber	7064	7287	70	67	4.3	3.7	316	320	11.8	12.1	107	85	77	72
Calypso	6471	7484	68	65	5.7	5.9	140	112	12.3	12.3	130	93	63	67
Timmo	8102	8225	70	74	3.2	1.8	258	261	12.0	12.1	120	85	84	85
Highbury	6175	6690	63	63	4.8	4.5	216	167	12.0	12.1	113	92	83	81
Sirius	6694	7336	70	72	4.4	3.9	352	332	12.2	12.7	104	122	72	77

*F_1 - Single application of Bayleton CF.

F_2 - Multiple application of Bayleton CF.

Cultivar.-- The choice of cultivar is the most significant factor in determining quality. Yield of flour can vary greatly depending on whether the cultivar is classified as a hard or soft wheat. Some fluctuation can occur in flour color depending on the level of extraction of flour. The Hagberg falling number is very much a function of cultivar and, even when no grain germination has taken place, alpha-amylase levels vary between cultivars grown in the same environment. Protein can vary by as much as one percentage point between cultivars in a trial (Greer).

Dough quality, as indicated by extensogram values, also varies greatly with cultivar. The overall combination of alpha-amylase levels and protein quantity and quality is reflected in bread quality which, again, can vary immensely.

In a general classification of varietal quality (N.I.A.B 1979/80) Copain and Bounty would fall into a bread-wheat category and Hobbit into a feed-wheat category. Armada would be intermediate in classification and would be regarded as a 'filler' wheat.

In the trial series presented here (Table 5) this variation in quality is quite extreme. The data represent portion of the results of a winter cultivar trial harvested in 1979. Yields were high with the feed wheat Hobbit significantly better than the others. The levels of flour extraction were reasonably acceptable. The Hagberg values were in excess of the arbitrary 160 level separating sprouted and non-sprouted wheat categories. Protein levels were quite low, with the high yielding feed-wheat considerably below the other three. The bread quality, in general, was poor. The 'filler' wheat Armada would be placed in this category but the cultivar Bounty apparently had not the capacity to produce acceptable bread at this level of protein content.

Table 5. Yield and quality of winter cultivars harvested in 1979.

Cultivar	Yield kg/ha	Flour Extraction %	Flour Color	Hagberg Falling Number	Protein %	Extensogram Area	Loaf Score %
Armada	7558	73	1.6	254	8.2	73	57
Hobbit	8892	64	0.6	218	7.0	84	10
Copain	7380	66	0.6	196	8.5	101	43
Bounty	7736	65	0.3	212	8.2	51	20

Discussion.

The modern European approach to wheat production aims at optimising all of the inputs in the system. The aim of the producer is the maximisation of yield. This approach should be acceptable to the processor if it does not interfere with quality.

Data abstracted from a trial programme in Ireland would seem to indicate that, in general, the producers efforts to optimise yield will be of benefit to the processor.

If the producer attempts to increase yield by earlier sowing he will end up with a grain sample of better color which shows little alpha-amylase activity.

In general, in Ireland, there is a critical upper limit to nitrogen fertilization beyond which yield does not increase. However, protein levels can be increased by increased fertilization and, if the producer could be compensated for the increased production cost, these higher protein levels could be financially beneficial to the processor by lessening his reliance on high-protein imported wheat.

An important aspect of the operation of high-yield production systems is the use of fungicides. The effect of increased levels of fungicide use can change the quality pattern in grain harvested from treated areas. However, the effects are relatively small and would be of little consequence when compared to the effect of fungicide on yield.

The major parameter in relation to grain quality improvement would seem to depend on the choice of cultivar. High yields can be obtained from wheats regarded as feed wheats; these wheats produce poor-quality bread in any circumstance. When protein levels are low, as in 1979, the quality standards of such wheats are disastrously low and they are of no value to the processor. In such circumstances any approach to quality improvement, such as the increased use of nitrogen fertilizer, might justify an effort by the processor to compensate the producer for increased input costs.

References

McCluggage, M.E., J.E. Anderson and R.R. Larmour, 1939. A comparison of the Allis-Chalmers and the Buhler automatic experimental mills. Cer. Chem. 16: 610-619.

Kent-Jones, D. W. and W. Martin, 1950. A photo-electric method of determining the color of flour as affected by grade, by measurements of reflecting power. Analyst. 75: 127-143.

Greer, E.N. 1963. Wheat for bread making. Agriculture (London), 70: 435-437.

N.I.A.B. 1979/80. Classified List of Cereal Varieties. Nat. Inst. Agr. Bot., Cambridge, pp.14.

POSSIBILITIES OF UTILIZING GENUS AEGILOPS FOR OBTAINING HIGH-QUALITY WHEAT FORMS

Bogdan Bochev and Violeta Doncheva
Bulgaria

Summary

As a result of studies carried out in the course of many years the effect of the genome composition of the Aegilops species upon some of the more important physical and chemical-technological qualities of the seed and the possibilities of transferring the genes which determine these qualites into common wheat (T. aestivum) by means of interspecific hybridization, have been determined.

It was established that the separate genomes acting independently in diploid species or interacting with each other in tetraploid and hexaploid Aegilops species and with the genomes of T. aestivum in intergeneric Aegilops-wheat hybrids, exert specific effect upon the qualitative indicators of grain and flour. The conclusion is drawn, that the genus Aegilops could be utilized in wheat breeding as valuable initial material for creating new, high yielding and high quality forms.

Introduction

The very close relationship of the genus Aegilops to Triticum and its very valuable biologic qualities have directed the attention of many researchers to studying most thoroughly this genus with a view to its practical utilization in the breeding of common wheat. At present, the studies regarding the chemical-technological and baking qualities of the Aegilops species and the specific effect of separate genomes on their formation, are limited. These studies are usually carried out with a limited number of Aegilops species (Ae. speltoides, Ae. squarrosa, Ae. ovata, Ae. triuncialis) and involve a small number of quality indicators (Tyuterev and others, 1975, Moustafaev, Huseinov, 1974, etc.). More thorough investigations of some physical, technological and baking qualities of 35 samples from the All-Union Plant-breeding Institute (VIR) belonging to 12 species were carried out by Semenova and others (1973).

The Institute of Genetics of the Bulgarian Academy of Sciences maintains a large collection of forms and species of the genus Aegilops of different origin. This material was thoroughly studied. The studies regarding the genome and chromosome homeology of these species with the species of the genus Triticum, their interaction in hybridization, the possibilities provided by genus Aegilops for the breeding of common wheat with a view of creating new, high yielding, high quality and resistant wheat forms, etc, are of great importance.

Institutes of Genetics and Soil Science and Yield Programming, Sofia.

The main purpose of this study was to determine the specific effect of separate genomes of Aegilops species upon some basic physical and chemical-technological qualities of their seeds and the possiblities of creating wheat forms of high quality, combining in their hereditary complex other valuable biologic and economic qualities.

Material and Methodology

The study was comprised of 79 samples belonging to 19 different species of the genus Aegilops: Ae. bicornis (S^b), Ae. caudata L. (C), Ae. comosa Sibth. et Sm (M), Ae. speltoides Taush (B S), Ae. squarrosa L. (D), Ae. umbellulata Zhuk. (C^u), Ae. uniaristata Vis. (M^u), Ae. ausheri Taush (S B), Ae. triuncialis L. (C^uE), Ae. triaristata Willd. (C^uM^t), Ae. crassa Boiss (DM^{cr}), Ae. ovata L. (C^uM^o), Ae. biuncialis (Will) Vis. (C^uM^b), Ae. columnaris Lhuk. (C^uM^o), Ae. variabilis Eig (C^uS^v), Ae. ventricosa Taush. (DM^v), Ae. cylindrica Host (CD), Ae. macrochaeta and Ae. turcomanica.

For the purpose of establishing the possibilities of transferring some valuable chemical-technological qualities of Aegilops species into common wheat by means of hybridization, the inheritance of these qualities in hybrid generations (F_3 to F_9) of the crosses between the species Ae. ovata, Ae. crassa and Ae. triuncialis and the varieties of wheat Bezostaya 1, Rannaya 12 (both high quality Soviet varieties) and IB01828 (an Italian, low-grade wheat variety with great potential productive possibilities) was studied. The Aegilops species and their crosses with T. aestivum were studied with regard to: weight of 1,000 seeds, protein content of seed after the method of Kjeldahl, sedimentation value of flour after the method of Poumpyanski, which is used widely as an indirect indicator of the strength and baking quality of flour (Poumpyanski, Semenova, 1969; Semenel and others, 1972), content of wet gluten and the specific sedimentation indicator, expressing the ratio between sedimentation value of flour and protein content of grain.

The inclusion of tetraploid Aegilops species possessing a common or homeologic genome in hybridization with T. aestivum, provided the possiblity of studying also, the specific effect of individual genomes of the parent Aegilops form upon the formation of the basic physical and chemical-technological qualities of grain and flour of the hybrids.

Results and Discussion

The data from the study of Aegilops species containing genome C indicate that this genome, when acting independently in the diploid species, determines medium weight of 1,000 seeds, low vitreousness, very good baking quality and relatively high protein content of seed (Table 1). When interacting with genome C^u, it raises slightly the protein content of seed and improves to some extent its baking qualities. The interaction of genome C with genome D affects considerable improvement of baking qualities, but in exchange for this, the protein content of seed decreases.

Table 1. Effect of genome C upon some physical and chemical-technological properties of Aegilops.

Species	Number of samples examined	Numbers of samples examined	Absolute weight (g)		Vitreousness (g)		Sedimentation value after Poumpyanski (ml)		Protein content of grain (%)	
			Variation	Average for the species	Variation	Average for the species	Variation	Average for the species	Variation	Average for the species
1	2	3	4	5	6	7	8	9	10	11
Ae. caudata	2	9, 78	9.2-13.4	11.3	7-12	10	49	49	24.50-27.02	25.76
Ae. triuncialis	23	3, 4, 19-39	10.9-17.1	14.1	3-26	9	18-64	40	26.35-31.43	27.95
Ae. cylindrica	3	79, 80, 81	11.5-16.0	13.0	8-10	9	48-60	58	22.88-24.85	23.65

Genome M in the diploid species determines medium weight of 1,000 seeds, low vitreousness, high protein content of seed and relatively high baking qualities (Table 2). As a result of its interaction with genome D of Ae. crassa, the weight of 1,000 seeds increases, but their vitreousness and protein content decrease and baking quality deteriorates to some extent. In all species, the interaction of genome M with genome C^u affects higher weight of 1,000 seeds and lower rate of flintiness, the only exception being Ae. columnaris in which vitreousness increases but baking qualities decrease.

Genome C^u, acting independently in diploid species, determines medium weight of 1,000 seeds, high vitreousness and protein content of seed and low baking qualities (Table 3). Its interaction with genome S^v effects considerable improvement of baking qualities and lower vitreousness and protein content of seed. The interaction of genome C^u with genome M effects different results, depending on the particular species. In most species it does not effect any change in the weight of 1,000 seeds. In Ae. triaristata, however, it effects a considerable increase of the weight of 1,000 seeds, and to much less extent, in Ae. biuncialis. The interaction of genome C^u with genome M, in all species, lowers vitreousness of seed and improves baking qualities, the protein content of seed remaining unaffected.

Genome D in diploid species determines medium weight of 1,000 seeds, relatively low vitreousness and protein content of seed and comparatively high baking qualities (Table 4). Its interaction with genome M does not effect any change in the weight of 1,000 seeds and vitreousness of seed.

In the species Ae. ventricosa baking qualities and protein content of seed remain unaffected. The interaction of genome D with genome C does not effect any considerable change in the weight of 1,000 seeds and their vitreousness and baking qualities; it raises insignificantly the protein content of seed.

The diploid species Ae. bicornis is of interest for wheat breeding because of the higher protein content of its seed (Table 5).

The species Ae. speltoides, Ae. macrochaeta and Ae. turcomanica are distinguished by high sedimentation values of flour, high protein content of seed but low weight of 1,000 seeds and low vitreousness.

The species Ae. uniaristata, as regards weight of 1,000 seeds, vitreousness and protein content of seed, is distinguished by moderate values.

The species Ae. aucheri is of interest for wheat breeding because of the high protein content of seed.

Table 2. Effect of genome C^u upon some physical and chemical-technological properties of *Aegilops*.

Species	Number of samples examined	Numbers of samples examined	Absolute weight (g)		Vitreousness (g)		Sedimentation value after Poumpyanski (ml)		Protein content of grain (%)	
			Variation	Average for the species	Variation	Average for the species	Variation	Average for the species	Variation	Average for the species
1	2	3	4	5	6	7	8	9	10	11
Ae. umbellulata	1	91		16.4		90		22	27.81	
Ae. variabilis	1	47		15.3		22		50	25.77	
Ae. ovata	5	1, 2, 16, 17, 96	15.5-23.0	18.1	30-58	39		44	24.67-29.36	27.43
Ae. triaristata	7	5, 40, 41, 42, 43, 44, 45	18.4-32.0	25.0	4-14	8	20-40	32	25.83-29.26	26.89
Ae. biuncialis	2	12, 92	16.0-24.5	20.2	22-100	61		31	26.75-27.77	27.26
Ae. columnaris	1	93		16.2		98		25		28.12
Ae. triuncialis	23	3, 4, 19, 39	10.9-17.1	14.1	3-26	9	18-64	40	26.35-31.43	27.95

Table 3. Effect of genome M upon some physical and chemical-technological properties of *Aegilops*.

Species	Number of samples examined	Numbers of samples examined	Absolute weight (g)		Vitreousness (g)		Sedimentation value after Poumpyanski (ml)		Protein content of grain (%)	
			Variation	Average for the species	Variation	Average for the species	Variation	Average for the species	Variation	Average for the species
1	2	3	4	5	6	7	8	9	10	11
Ae. comosa	4	82, 83, 86, 87	8.5-10.5	9.4	12-29	19		95	25.14-28.78	27.28
Ae. crassa	3	48, 49, 50	15.4-23.8	20.6	3-10	6	62-75	69	21.00-22.92	22.27
Ae. ovata	5	1, 2, 16, 17, 96	15.5-23.0	18.1	30-58	39		44	24.67-29.36	27.43
Ae. triaristata	7	5, 40, 41, 42, 43, 44, 45	18.4-32.0	25.0	4-14	8	20-40	32	25.83-29.26	26.89
Ae. biuncialis	2	12, 92	16.0-24.5	20.2	22-100	61		31	26.75-27.77	27.26
Ae. columnaris	1	93		16.6		98		25		28.12
Ae. ventricosa	3	51, 52, 95	12.5-12.9	12.8	2-6	4	70-95	83	27.12-27.61	27.34

Table 4. Effect of genome D upon some physical and chemical-technological properites of *Aegilops*.

Species	Number of samples examined	Numbers of samples examined	Absolute weight (g)		Vitreousness (g)		Sedimentation value after Poumpyanski (ml)		Protein content of grain (%)	
			Variation	Average for the species	Variation	Average for the species	Variation	Average for the species	Variation	Average for the species
1	2	3	4	5	6	7	8	9	10	11
Ae. squarrosa	10	53 54, 55, 56, 57, 58, 59, 61, 62, 64	11.3-16.5	12.5	3-15	8	25-76	45	20.61-22.52	21.44
Ae. ventricosa	3	51, 52, 95	12.5-12.9	12.8	2-6	4	70-95	83	27.12-27.61	27.34
Ae. crassa	3	48, 49, 50	15.4-23.8	20.6	3-10	6	62-75	69	21.00-22.92	22.27
Ae. cylindrica	3	79, 80, 81	11.5-16.0	13.0	8-10	9	48-60	58	22.88-24.85	23.65

Table 5. Effect of genome composition upon some physical and chemical-technological properties of *Aegilops*.

Species	Number of samples examined	Numbers of samples examined	Absolute weight (g)		Vitreousness (g)		Sedimentation value after Poumpyanski (ml)		Protein content of grain (%)	
			Variation	Average for the species	Variation	Average for the species	Variation	Average for the species	Variation	Average for the species
1	2	3	4	5	6	7	8	9	10	11
Ae. bicornis	1	89		12.8		–	–			29.53
Ae. macrochaeta	1	8		17.5		24.0	73			32.64
Ae. speltoides	9	6, 66, 67, 68, 70, 71, 72, 73, 75	4.8-7.6	6.4	3-10	5	44		24.38-29.53	26.35
Ae. aucheri	1	69		7.0		4	–			27.58
Ae. turcomanica	1	94		17.0		4	81			24.17
Ae. uniaristata	1	46		14.7		18	–			24.82

Hybrids of *Aegilops* with *T. aestivum*

Ae. ovata x Bezostaya 1.--Data regarding studies hybrid progenies of this crossing are presented in Table 6.

These data indicate that the weight of 1,000 seeds of these hybrid generations and progenies varies widely --from 20.8 to 54.5 g. Along with forms producing smaller seed, there are also forms producing larger seed of a weight per 1,000 seeds of over 40 g (4.76% in F_7 to 41.6% in F_8).

Higher protein content of seed, over 18%, is an especially valuable quality of most of the studied hybrid progenies. It should be mentioned also that higher protein content in seed was not only in the initial hybrid generations (F_3-F_4) but also in the higher hybrid generations (F_7-F_9). The percentage of hybrid progenies of these generations producing seed of a protein content of over 18% varies from 10.52 to 66.6.

The sedimentation value of flour of hybrid progenies varies within wide limits -- from 20 to 76 m. A sedimentation value of flour of more than 50 ml. was established in 14 to 80% of the samples of separate hybrid generations; this shows that these samples fall into the group of wheats with good and exellent technological and baking qualities of flour. A considerable number of hybrid progenies also have higher content of wet gluten --over 40%.

Results of studied hybrid progenies indicate, that hybridization of *Ae. ovata* species with the high quality wheat variety Bezostaya 1 provides excellent possibilities for breeding valuable, high quality wheat varieties.

Ae. ovata x Rannaya 12.--Data regarding the basic physical and chemical-technological qualities of the studied hybrid progenies of crossing are presented in Table 7.

These data indicate that the weight of 1,000 seeds of single progenies varies within wide limits. In comparison with the preceding cross, the number of hybrid progenies having a weight of 1,000 seeds of over 40 g. is smaller, which probably results from the variety Rannaya 12. A large number of the studied progenies of this cross also have higher protein content in seed, over 18%, the average for the variety Rannaya 12 being from 14.4% to 15.6%. It should be pointed out that some progenies of hybrid generations F_7-F_9 have seeds with a protein content of over 20%.

A considerable part of hybrid progenies (from 14.28% to 66.6%) have flour with a sedimentation value of over 50 ml. Proceeding from the fact that a large part (from 7.14% to 48.0%) of these progenies are distinguished by high (over 3) specific sedimentation indicators, they could be rated among the wheat varieties with very good and exellent qualities. This conclusion is confirmed also by the data regarding their high content of wet gluten (over 40%).

Table 6. Physical and chemical-technological properties of Ae. ovata x Bezostaya 1 hybrids.

Hybrid generation	Number generation examined	Weight of 1,000 seeds (g)		Protein content of seed (%)		Sedimentation value (ml)		Specific sedimentation indicator		Wet gluten (%)	
		Variation	Average	Variation	Average	Variation	Average	Variation	Average	Variation	Average
1	2	3	4	5	6	7	8	9	10	11	12
F_3	12	29.4-42.8	35.8	15.9-24.5	20.7	41-56	50.2	2.58-3.37	2.85	-	-
F_4	28	21.6-49.2	33.1	14.9-24.3	20.4	31-75	52.3	1.79-3.83	2.61	-	-
F_5	8	28.5-45.5	36.9	15.9-21.4	18.5	36-55	43.5	1.68-3.31	2.38	-	-
F_6	11	22.4-41.4	35.0	15.3-20.4	17.9	24-67	35.4	1.28-3.68	1.97	32.0-43.2	35.4
F_7	31	20.9-42.9	27.5	13.2-21.5	16.4	24-78	40.9	1.42-3.88	2.48	23.8-45.4	34.3
F_8	31	21.6-54.5	34.1	12.6-22.5	16.5	20-69	43.5	1.57-4.20	2.61	22.5-44.9	34.[illegible]
F_9	6	30.2-40.3	35.2	15.0-17.7	16.9	28-61	44.8	1.87-3.49	2.64	27.0-40.0	36.5

Table 7. Physical and chemical-technological properties of Ae. ovata x Rannaya 12 hybrids.

Hybrid generation	Number generation examined	Weight of 1,000 seeds (g)		Protein content of seed (%)		Sedimentation value (ml)		Specific sedimentation indicator		Wet gluten (%)	
		Variation	Average	Variation	Average	Variation	Average	Variation	Average	Variation	Average
1	2	3	4	5	6	7	8	9	10	11	12
F_3	5	30.7-35.2	32.3	14.9-22.2	17.2	25-54	41.6	1.12-3.12	2.51	-	36.6
F_4	14	24.7-42.3	35.8	15.0-19.2	17.5	30-54	40.6	1.74-3.09	2.31	30.0-44.7	36.[illegible]
F_5	12	25.9-36.6	31.3	18.7-24.7	22.4	30-91	56.3	1.28-4.04	2.62	39.0-50.4	44.[illegible]
F_6	15	26.2-39.5	33.1	15.1-17.8	16.7	24-65	37.3	1.52-3.65	2.23	25.1-37.9	34.4
F_7	16	30.1-42.0	33.4	12.1-19.8	16.0	24-74	45.4	1.44-3.73	2.82	30.5-42.0	35.0
F_8	25	33.6-41.8	31.9	11.8-20.7	16.0	22-60	45.4	1.36-3.76	2.86	29.5-45.8	38.1
F_9	11	25.1-43.2	35.0	12.9-20.4	16.1	22-58	39.7	1.39-4.34	2.53	25.0-40.0	32.2

A general conclusion could be drawn on the basis of the data presented; namely, that high-quality and high-yielding wheat varieties could be created by means of hybridization of Ae. ovata with the Rannaya 12 wheat variety.

Ae. cressa x Bezostaya 1.--The data regarding studied hybrid progenies of this cross are presented in Table 8.

These data indicate that the hybrid progenies of this cross have relatively high average weight of 1,000 seeds in comparison with the progenies of the cross Ae. ovata x Bezostaya 1. Apparently, in this case, this could be attributed to the specific effect of the Aegilops species. Similar to the hybrid progenies of Ae. ovata x Bezostaya 1 and Ae. ovata x Rannaya 12, the progenies of this cross have higher protein content. Some 16% to 100% of the hybrid progenies of separate hybrid generations have a protein content in the seed of over 17%. A characteristic feature of these progenies, differentiating them from the generations of the cross of Ae. ovata is that their higher protein content in the seed is combined to maximum degree with high sedimentation value of flour and larger quantity of high quality gluten (unpublished data). Apparently, these valuable qualities of these hybrids result from the specific effect exerted by the Aegilops species, more precisely, from the action of genome D and its favorable interaction with the genome of the Bezostaya 1 wheat variety.

Ae. crassa x Rannaya 12.--The results obtained from studying the hybrid progenies of this cross indicate that these progenies have smaller weight of 1,000 seeds (Table 9) in comparison to the progenies of the same cross with the variety Bezostaya 1. This should be attributed to the action of variety Rannaya 12, which has smaller seeds.

A considerable part of the progenies of this cross (9% to 40%) have large seeds (over 40 g). As regards protein content of seed, essential differences between the progenies of these two crossings are not established. The protein content of seed varies widely from 13.8% to 22.5% (Table 9).

Higher protein content in seed is established in the initial generations from F_3 to F_5; more than 71% of the studied progenies of these generations have seed with a protein content of over 17%. Forms producing seed of higher protein content are found also in F_6 and F_7 hybrid generations, but their number is smaller in comparison to the Ae. crassa x Bezostaya 1 cross. In these hybrid progenies, high protein content of seed combines to a lesser degree with high sedimentation value of flour and large quantity of high quality gluten, although the favorable affect of genome D of species Ae. crassa is apparent also in this crossing.

Table 8. Physical and chemical-technological properties of *Ae. crassa* x Bezostaya 1 hybrids.

Hybrid generation	Number generation examined	Weight of 1,000 seeds (g)		Protein content of seed (%)		Sedimentation value (ml)		Specific sedimentation indicator		Wet gluten (%)	
		Variation	Average	Variation	Average	Variation	Average	Variation	Average	Variation	Average
1	2	3	4	5	6	7	8	9	10	11	12
F_3	12	34.0-45.4	39.4	18.2-22.6	19.9	40-72	55.4	2.31-3.68	2.81	-	-
F_4	23	26.0-45.2	41.2	14.9-20.9	18.3	25-65	42.9	1.40-3.45	2.47	37.6-48.6	36.9
F_5	15	28.6-45.9	36.4	13.7-21.4	17.8	35-65	47.1	1.93-3.45	2.64	31.0-48.6	39.1
F_6	16	27.2-38.9	33.6	14.4-20.3	16.4	26-68	49.0	1.61-4.17	2.95	34.1-44.7	39.1
F_7	25	37 2-50.9	41.6	12.7-18.3	15.9	21-56	40.5	1.55-3.62	2.58	23.3-35.2	36.7
F_8	26	33.9-51.2	43.6	12.7-22.3	17.0	26-65	42.0	1.16-3.94	2.46	30.8-41.6	36.1

Table 9. Physical and chemical-technological properties of *Ae. crassa* x Rannaya 12 hybrids.

hybrid generation	Number generation examined	Weight of 1,000 seeds (g)		Protein content of seed (%)		Sedimentation value (ml)		Specific sedimentation indicator		Wet gluten (%)	
		Variation	Average	Variation	Average	Variation	Average	Variation	Average	Variation	Average
1	2	3	4	5	6	7	8	9	10	11	12
F_4	5	27.3-48.0	37.5	19.1-22.5	20.7	44-57	48.3	1.96-2.98	2.41	-	-
F_5	7	26.7-41.5	35.4	16.6-21.9	18.6	35-54	39.0	1.55-2.63	2.09	33.4-45.4	40.1
F_6	22	31.5-41.6	34.5	13.8-18.9	16.3	25-58	37.0	1.43-3.29	2.28	27.8-42.5	34.4
F_7	17	27.1-44.8	37.9	14.3-17.9	16.8	25-63	39.5	1.96-4.04	2.49	28.9-41.3	34.6

Ae. crassa x IBO-1828.--Data regarding the qualitative indicators of the progenies of this cross are presented in Table 10.

These data indicate that a larger part of the studied progenies of F_7, F_8 and F_9 generations have large seed, over 40 g. per 1,000 seeds, which most probably is effected by the Aegilops species. The protein content of seed varies widely, from 13.8% to 24.0%. Its maximum values, however, are smaller in comparison with those of the progenies of Ae. ovata x Bezostaya 1 and Ae. ovata x Rannaya 12 crosses. This, most probably, results from the action of genome D of the Aegilops species. Nevertheless, a considerable part of a studied progenies (from 4.80% to 62.5%) of individual hybrid generations have seed of high protein content -- over 17.0%, some of them even higher than 18.0% (4.80% to 37.5%).

The most characteristic feature of the hybrid progenies of this cross is that the relatively high protein content of their seeds is favorably combined with high sedimentation value of flour and high content of good quality gluten. These data indicate wide prospects of creating high yielding and high quality wheat varieties by means of intergeneric hybridization of Aegilops with wheat and proper selection of parent forms, even in cases when wheat varieties of poor technological and baking qualities are utilized for hybridization.

Ae. triuncialis x Bezostaya 1.--Data regarding the quality indicators of the hybrid progenies of this cross are presented in Table 11.

These data indicate, that the greater part of the hybrid progenies of this cross have small seeds. An insignificant number of progenies have larger seeds with a weight of over 40 g./1,000 seeds.

The protein content of the seed of separate hybrid generations and their progenies varies but slightly. The maximum protein content of the seed of studied progenies does not exceed 19.4%. Hybrid progenies of F_6 to F_7 generations producing seed of high protein content are considerably less in number in comparison to those of the crosses between other Aegilops species and the Bezostaya 1 wheat variety. These data indicate, that the species Ae. triuncialis transfers its high protein content to a less degree into the hybrid progenies. The absolute values of flour sedimentation, specific sedimentation and quantity and quality of gluten are also considerably lower.

The results of this study indicate, that species Ae. triuncialis appears to be less reliable for hybridization with T. aestivum and creation of promising, high quality new wheat forms.

Table 10. Physical and chemical-technological properties of Ae. crassa x IB01828 hybrids.

Hybrid generation	Number generation examined	Weight of 1,000 seeds (g)		Protein content of seed (%)		Sedimentation value (ml)		Specific sedimentation indicator		Wet gluten (%)	
		Variation	Average	Variation	Average	Variation	Average	Variation	Average	Variation	Average
1	2	3	4	5	6	7	8	9	10	11	12
F_4	5	32.3-41.7	36.6	16.8-24.0	20.48	65-92	77	3.59-4.87	4.17	-	-
F_5	8	28.4-39.7	36.6	14.7-18.5	16.8	19-39	31.6	1.03-2.60	1.90	32.4-44.1	[illegible]
F_6	34	24.3-48.3	37.1	13.9-18.7	16.4	26-64	46.7	1.42-4.47	2.86	24.8-41.9	35.9
F_7	34	30.0-50.7	39.8	13.8-19.5	16.8	19-60	43.3	1.19-4.20	2.58	26.1-47.0	[illegible]
F_8	29	27.4-49.4	41.3	14.0-17.9	14.8	29-58	43.1	1.62-4.66	2.96	25.2-42.8	[illegible]
F_9	7	36.0-46.9	42.7	14.5-17.3	15.9	28-52	38.8	1.71-3.21	2.40	28.5-37.1	[illegible]

Table 11. Physical and chemical-technological properties of Ae. triuncialis x Bezostaya 1.

Hybrid generation	Number generation examined	Weight of 1,000 seeds (g)		Protein content of seed (%)		Sedimentation value (ml)		Specific sedimentation indicator		Wet gluten (%)	
		Variation	Average	Variation	Average	Variation	Average	Variation	Average	Variation	Average
1	2	3	4	5	6	7	8	9	10	11	12
F_4	10	30.7-42.5	35.4	13.8-19.2	15.2	18-45	32.1	1.22-2.68	2.11	-	-
F_5	3	29.9-33.9	32.3	15.8-19.1	17.8	26-49	35.0	1.57-2.57	1.95	-	-
F_6	10	22.3-42.0	29.1	14.6-19.4	16.7	26-65	37.5	1.32-3.82	2.26	30.8-38.5	36.2
F_7	18	27.5-37.8	32.0	14.0-17.1	15.7	30-54	39.8	1.93-3.62	2.58	27.1-43.5	32.0
F_8	15	34.1-42.6	36.9	15.5-18.6	16.7	28-50	41.9	1.60-3.41	2.51	30.0-40.0	34.9

Table 12. Physical and chemical-technological properties of parent forms.

Name of species (variety)	Weight of 1,000 seeds (g)		Protein content of seed (%)		Sedimentation value (ml)		Specific sedimentation indicator		Wet gluten (%)	
	Variation	Average	Variation	Average	Variation	Average	Variation	Average	Variation	Average
1	2	3	4	5	6	7	8	9	10	11
Ae. ovata	14.1-18.1	16.58	25.3-29.1	27.3	44-65	49.4	1.51-2.56	1.82	52.0-63.6	56.2
Ae. crassa	16.0-27.2	20.82	22.3-26.4	24.8	49-86	69.1	1.98-3.29	2.62	53.0-63.6	57.4
Ae. triuncialis	14.1-18.0	15.44	25.1-27.9	25.9	33-50	38.2	1.18-1.99	1.49	54.1-63.6	58.6
Bezostaya 1	37.8-44.4	40.80	14.3-15.7	15.3	41-59	52.0	2.80-3.77	3.41	28.8-36.2	32.4
Rannaya 12	31.0-44.8	37.37	14.2-15.6	14.8	35-46	40.2	2.39-3.23	2.83	29.8-35.1	33.6
IBO1828	25.2-40.9	33.67	14.6-17.8	15.8	26-31	29.0	1.68-1.96	1.83	24.0-31.0	28.1

Conclusion

As a result of this study, it is established, that the examined Aegilops species and samples, as regards basic physical, chemical-technological and baking qualities, vary within wide limits. The separate genomes of these species exert specific effect upon the chemical-technological and baking qualities. Genomes M^u and C^u in Aegilops species exert the most favorable, positive effect for the formation of large seed of high protein content. Genome D in Aegilops species determines high baking qualities of flour. Genome C exerts smaller positive effect upon baking qualities.

Under the influence of the genome of Ae. ovata and of its interaction with the genomes of the Soviet, high quality wheat varieties Bezostaya 1 and Rannaya 12, in the hybrid progenies of their crosses are established new forms producing seeds of high protein content and very good and exellent technological and baking qualities. Better results have been obtained from crossing Ae. ovata with Bezostaya 1.

Species Ae. crassa in hybridization with high quality, as well as low quality wheat varieties, exerts a very strongly expressed positive effect as regards formation of large seeds of high technological and baking qualities and high protein content.

Species Ae. triuncialis appears to be a less reliable component of intergeneric hybridization with T. aestivum for the purpose of creating new wheat forms producing seed of high quality possessing high technological and baking qualities.

As a result of this study, it is established that the species of genus Aegilops are of special interest as very valuable initial material for breeding new wheat forms producing seed of high protein content and high technological and baking qualities, on account of which they should be more widely included in wheat breeding programs.

THE INTERNATIONAL WINTER X SPRING WHEAT RESEARCH AND GRADUATE TRAINING PROGRAM

W. L. McCuistion, W. E. Kronstad,
F. A. Cholick, and N. H. Scott
United States

Abstract

Genetic diversity is the life blood of all plant improvement programs. The concept of systematically mixing of the winter and spring gene pools is providing promising usable genetic variation to breeders in both winter and spring production regions of the world. Historically the most publicized cross involving winter and spring type wheats was made by CIMMYT scientists between 'Norin 10-Brevor' and 'Gabo'. The progeny resulting from this cross combined short stiff straw with daylength insensitivity and were more responsive to improved management practices. The impact that these cultivars had on increasing food production has been clearly identified. What is frequently overlooked is the stimulation this technological breakthrough had on agricultural research throughout the world.

As plant breeders have achieved higher yield levels, it is becoming increasingly apparent that additional genetic variability will be required. Certainly, as demands continue for increased food production, greater emphasis must be placed on production areas where such factors as limited moisture, winter survival, frost tolerance and numerous disease complexes limit grain yield. Also, under cultural practices varying from intercropping or multiple cropping to summer fallowing, early maturity will be important. By taking advantage of different vernalization requirements and daylength responses plus favorable gene combinations for resistance or tolerance to the many limiting factors, may well be where the winter x spring crossing program can provide the necessary genetic diversity for an increased and stable grain yield.

Of equal importance will be the training of sufficient numbers of highly motivated young scientists in various aspects of agriculture, thereby strengthening national programs. There is a need for strong training programs at the M.S. and Ph.D. levels to complement the practical training received at the various international centers such as CIMMYT. Currently 60 scientists from many different countries have completed advanced degrees in breeding, production and plant pathology at Oregon State University. The fact that there is a strong international cereal research program at Oregon State University has contributed significantly to the graduate training program. Many of the former students are currently cooperators in the winter x spring program and carry major responsibility in their respective country programs.

Oregon State University, Corvallis

It is imperative that worldwide linkages be maintained and expanded through the dissemination and exchange of germplasm, the use of disease and insect surveillance nurseries, the training of young scientists and through sharing of information at various conferences. It is only through such activities that the agricultural scientists can help shift the balance in favor of more food production and take care of the extra four billion people who will be present by the year 2015.

Winter x Spring Wheat Research

The International Wheat Research Program at Oregon State University (OSU) was initiated in 1967 from grant funds provided by the Rockefeller Foundation and the United States Agency for International Development (USAID). The association started through the University Cooperative Exchange of scientists concerned with the Wheat Improvement Program in Turkey. The winter x spring wheat program at Oregon State University has evolved through close collaborative efforts with the International Maize and Wheat Improvement program (CIMMYT) in Mexico. Frequent exchange of personnel, germplasm and information between staffs of OSU and CIMMYT has provided increased genetic variability from these winter x spring crosses. This variability is noted in response to different fertility levels, daylength requirements and favorable gene combinations for resistance and tolerance to the many limiting factors generally occurring in wheat production.

The objectives of the winter x spring wheat program are: 1) the creation of genetic variability; 2) the exchange of germplasm and information; 3) the establishment of lines of communication between wheat breeders; and 4) the provision of strong graduate programs for future leaders in cereal breeding.

The segregating populations resulting from winter x spring crosses are evaluated from winter planting at Toluca in the mountains of Mexico and three diverse sites in Oregon having 200, 500 and 1000 mm of annual rainfall. Variations in climatic conditions, soil types, management practices, crop rotations and disease complexes at these sites are similar to many of the winter wheat growing regions of the world.

The most promising bulk populations from F_5 and later generations are evaluated in preliminary yield trials, included in the 250 entry International Winter X Spring Wheat Screening Nursery (IWSWSN) and distributed to cooperators around the world. Of the 90 cooperators in 48 countries receiving the sixth IWSWSN, a total of 80% returned data or reported some hazard that prevented the collection of information. The majority of these locations are at latitudes greater than 30° north or south. Exceptions to this rule are those locations between 0 and 30° latitude located at

higher altitudes, commonly in mountainous regions. In one or two specific cases, the nursery is being distributed to a cooperator who is interested in searching for resistance to a major disease problem. Cooperating locations have been grouped regionally into three major rainfall zones as presented in Table 1.

Table 1. Regional distribution of nursery locations within the three designated rainfall zones.

World regions	Locations	Rainfall zones		
		<400mm	400-650mm	>650mm & irr.
Asia	8	--	6	2
Middle East	13	6	5	2
East Europe	15	3	11	1
Western Europe	7	2	4	1
Africa	4	3	1	-
North America	21	4	5	12
South America	12	2	6	4
South Pacific	2	1	-	1

The Middle East Region had the largest number of low rainfall sites (<400mm). These sites require cold tolerance ranging from late spring frost to sub-freezing temperatures down to -10°C. The largest number of cooperating locations (38) fit into the intermediate rainfall zone (400-650mm). The major winter cereal regions in the world do not exceed 650mm of annual rainfall. Several of the high rainfall sites in the USA, representing each of the major winter cereal regions were chosen to provide optimum climatic conditions for selection of various desired characters such as winterhardiness, drought tolerance, and resistance for the most important diseases.

Although the nursery is planted in small nonreplicated plots, and is not considered a yield trial, the reported yields from a number of locations give some indication of yield potential. The nursery provides three plot positions at each location for inclusion of the best locally adapted cultivar. It was encouraging to observe certain winter x spring selections at each location that were equal or superior to the local check varieties as shown in Table 2. There were eight sib lines of the cross P101/Anza occurring in the top 25 selections for yield potential when summarized over all locations. Although the average yield for the sibs was in most cases not higher than the local check, certain sib lines were significantly higher at each location. II57-59/Odzi has also been a good yielding line in previous nurseries.

A number of advanced lines have been selected for superior agronomic performance over all locations reporting. Several of these are listed in Table 3. A total of twenty-four of these selections have been placed in an international winter x spring replicated yield trial and will be distributed to selected cooperators during the coming year. These lines will be tested against the local checks to observe their adaptation to the local climatic conditions and their overall yielding ability.

Table 2. Highest yielding lines over all locations reporting on 6th IWSWSN, 1979-80.

Entry no(s).	Pedigree	KAB[1/] AFG	TEMU[2/] CHL	KRAK[3/] POL	OREG[4/] USA
92	Bez/Era//LOH1/Dirk	5200	2401	3184	7031
128	An/Hys	6700	4502	3980	6314
9,37,38,39, 166,169,172, 175	P101/Anza	5500	3380	5205	7860
243,244	Ymh/Hys	5450	4726	6545	8239
206,209	II58-57/Odzi	3900	4536	6822	6312
	Local check	4750	4189	5749	8529

1/ Kabul, Afghanistan
2/ Temuco, Chile
3/ Krakow, Poland
4/ Corvallis, Oregon

Table 3. Selections for superior agronomic performance over all locations reporting. 6th IWSWSN -- 1979-80.

Entry no.	Pedigree	Days to flower	Winter-hardiness	<400mm	400-650mm	>650mm
101	II 18899/Tpr/2/ C0652643	*		*	*	*
105	Ptc/Y54//Tzpp/ Nar/3/Sct/Lcr	*		*	*	*
126	Jar//Gns/Lp	*	*	*	*	*
1	Bolal	*		*	*	*
2	Roussalka	*	*	*	*	*
4	Bezostaja		*	*	*	*
86, 90,91	Smb/Hn4	*	*			
144, 145	Hys//Drc*2/7C	*	*			
206, 210	II 57-59/Odzi	*	*			

The most resistant lines to Puccinia striiformis, recondita and graminis tritici are reported in Table 4. Advanced line II 57-59/Odzi, just referred to in Table 2 for yield potential, also has expressed good general resistance for stripe and leaf rust. Selection CD*/3/MD//MCM/EX, although expressing some variability among sister lines, is generally resistant to stripe and leaf rust over all locations reporting. Several crosses with the winter parent Bezostaja have expressed a high level of resistance to the three rusts.

Table 4. Most resistant lines to P. striiformis, recondita and graminis tritici over all locations reporting. 6th IWSWSN -- 1979-80.

Entry no.	Pedigree	Highest reaction[1/] P. strii.	P. rec.	P. gr. tri.
206	II 57-59-Odzi	10MR	20S	
225	Ymh/Tob//Mcd	50X	30X	
28	Bez/Nad//Kzm	30MS	30MR	
92	Bez/Era//LOH1/Dirk	20S	30MS	
93	An//Sn64/SS2	40S	20MS	
67-75	CD*3/3/Md/Mcd/Ex	20MS-50S	20MR-20MS	
94,95, 214	Pch/3/KT54A/N10B// KT54B/4/NAR59			50MS-60S
59	F5 TJB845/1			30MS
6	Bez/Sn64//Dibo			30S

[1/] The disease observations represent the highest reaction recorded by those cooperators returning data.

The variety Bezostaja has maintained a good level of resistance to stem rust, but has shown increasing susceptibility to stripe and leaf rust. An F_5 selection, TJB845/1, from Dr. Bingham's program in Cambridge, England has also expressed good tolerance when exposed to heavy attacks of stem rust. Since stem rust does not develop under the normal climatic conditions in Oregon, the segregating generations from the winter x spring crosses are being evaluated in the CIMMYT program in Toluca, Mexico. The same populations are now being screened in Oregon and Mexico for the three rusts with the objective of combining resistance genes in desirable phenotypes. Future populations will also be screened at Izmir and Ankara, Turkey.

The reactions of specific lines to Erysiphe graminis tritici are reported in Table 5 for the specific locations of Passo Fundo, Brazil; Cambridge, England; Thessaloniki, Greece; Georgia, USA; and Zagreb, Yugoslavia. The results of a number of locations indicate a wide variation in races or biotypes for Erysiphe graminis disease. The first five entries in this table occurred in the top 25 selections over all locations for both Erysiphe graminis and Septoria tritici. The selection CD*3/3/MD//MCM/EX, reported to be resistant to stripe and leaf rust in Table 4, was observed to have resistant reactions at all locations except Atlanta, Georgia. Selection II 62-61/3/1453/Odin//CI13431 and a sister line of Alba/Gaines//Frontana/Sorora 64 were the only two lines expressing a resistance equivalent to the check variety Holly at the Georgia location.

Table 5. Reactions of specific lines to Erysiphe graminis at specified locations. 6th IWSWSN -- 1979-80.

Entry no(s).	Pedigrees	P.Fun BRA	Cmb GBR	Thes GRC	GA USA	Zag YUG
6	Bez/Sn64/Dibo	6[1/]	-	7	9	6
47	II 62-61/3/1453/ Odin//CI13431	9	4	4	2*	4
110	Cleo/Pch	5	3	7	-	4
142	Fgo/Joss	5	2	6	9	6
195	An/Nai/3/Su92/ CI13645//Inia	5	3	3	9	8
67-74	CD*3/3/Md/Mcm//Ex	5	3(0*)[2/]	3	9	3(1*)
62-78	Bez/Tob//8156	7	0	6	9	7
192-194	Alba/Gns//Fn/Sn64	6	4	6(3*)	9(2*)	7(4*)
Local check		8	3	9	1	1

[1/] 0=no infection; 9=ear infection.
[2/] ( )=most resistant reaction among the sib lines of this cross.

Reactions to Septoria tritici were also slightly variable at the different locations of Gembloux, Belgium; Chilean, Chile; Seoul, Korea; Oklahoma, USA; and Corvallis, Oregon, USA as shown in Table 6. Although the selections listed did not express a high level of resistance at all locations reporting, these lines were significantly better than the other entries in the nursery.

Table 6. Reactions of specific lines to Septoria tritici at specified locations. 6th IWSWSN -- 1979-80.

Entry no(s).	Pedigrees	Gemb. BEL	Chil. CHL	Seol. KOR	Okla. USA	Oreg. USA
6	Bez/Sn64/Dibo	5	0	6	6	3
47	II 62-61/3/1453/ Odin//CI13431	7	5	2	6	4
110	Cleo/Pch	4	6	3	7	3
142	Fgo/Joss	4	3	4	6	5
195	An/Nai/3/Su92/ CI13645//Inia	5	0	4	6	5
188-191	Alba/Gns//Fn/Sn64	6(3*)	7	4	5	5
156,158	Ymh/HN7	7	4	4	5	4
Local check		7	6	5	8	4

[1/] 0=no infection; 9=ear infection.

Winter and spring wheat breeding lines derived from crosses of winter x spring wheats are significantly superior to the winter x winter and spring x spring cultivars being developed in Oregon and Mexico, respectively. Marked increases are being observed in yield potential and resistance to the major cereal diseases. Communications from many cooperators throughout the world further confirm the fact that winter x spring crosses are providing new and valuable sources of genetic variability for use in wheat improvement.

Graduate Student Training Program at Oregon State University

Training is one of the most essential components of the Cereal Improvement Program at OSU. The development of strong training programs at the M.S. and Ph.D. levels are needed to complement the practical training received at the various international centers. The students accepted for advanced training are carefully selected using recommendations from well qualified international cooperators. The students are bright, gifted and dedicated with a proven work record in their own country prior to arrival at OSU.

Currently more than 60 scientists from many different countries have completed advanced degrees in breeding, crop production, plant pathology, weed control and soil fertility at OSU. Many of the former students are currently cooperating in the winter x spring program and carry major responsibilities for research in their respective country programs. It is essential that leadership skills be developed and that professional attitudes be instilled in the minds of the students. The training program must be geared to the needs of the international students in order that they be prepared for scientific research in their respective countries. Although there is need for flexibility in the programs, high academic standards are maintained.

Leadership is developed by assigning students responsibilities for various phases of the total research program in addition to their thesis research. Direct involvement in the daily activities of an aggressive breeding program builds experience and confidence that proves valuable upon returning to positions of responsibility in the students' own countries.

It is also essential that each student have an appreciation of the philosophy and techniques of extension systems. Possibly the weakest link in most agricultural programs in the developing world is the extension system. Lack of a viable program to move known technology from the research institutes to the farm level is a major hinderance to agricultural improvement. An attempt is made by the OSU cereal program to familiarize the students with the state extension system, to visit farmers and their families on progressive farms where research results are being applied and promote a team approach to integrated research and extension.

A positive result of the graduate training program has been the lasting relationships which have developed between the former students

and the faculty and staff. Contacts are maintained through occasional correspondence and, in some instances, faculty members are able to visit various countries and assist in developing programs. Such visits not only reinforce the young scientist's confidence in himself, but frequently roadblocks can be removed by visiting with government officials either in the particular country or while the officials are touring the United States.

It is imperative that worldwide linkages be maintained and expanded by the dissemination and exchange of germplasm, the use of disease and insect surveillance nurseries, training of young scientists and through sharing of information at various conferences. There are numerous national, regional and international nurseries available to cereal breeders throughout the spring and winter regions. There is a major effort by all of the regional and international agencies to coordinate distribution of germplasm and provide this material to any and all cooperators. It is only through these various activities that the agricultural scientists can help shift the balance in favor of more food production and take care of the extra four billion people who will be present by the year 2015.

PERFORMANCE OF HIGH PROTEIN LINES IN INTERNATIONAL TRIALS

S. L. Kuhr and V. A. Johnson
United States

Abstract

The high protein-high lysine winter wheat observation nursery was organized in 1974 by the Nebraska Agricultural Experiment Station and the Science and Education Administration, U.S. Department of Agriculture, under a contract with the Agency for International Development, U.S. Department of State.

The nursery is intended to provide breeders with germplasm with elevated levels of protein and/or lysine. It also tests the degree of expression of the high protein and high lysine traits in different environments.

A prime concern of breeders who use the high protein germplasm is the agronomic worth of the lines. Selection pressure has been applied in Nebraska to obtain lines in which elevated grain protein and/or lysine is combined with acceptable yield potential and reduced plant height.

The 1976 nursery consisting of 382 experimental lines and four replicated check varieties was distributed to 26 sites in 17 countries. Statistical analyses were performed on data from seven sites at which all 402 entries were harvested.

The 1977 nursery was distributed to 32 sites in 22 countries. It was comprised of 176 experimental lines and four replicated check varieties. Data received from six sites at which all 196 entries were harvested were analyzed statistically.

Eight experimental populations which had higher protein levels than Lancota (the elevated-protein check) along with relatively good lysine values were identified in the 1976 nursery. The populations ranged in grain yield from 39.1 to 45.2 q/ha compared with 44.4 q/ha for Bezostaya 1. They ranged in height from 94 to 101 cm compared with 94 and 107 cm for Bezostaya 1 and Lancota, respectively.

The populations were tested a second time in the 1977 nursery. Statistical analyses revealed that seven of the populations again equalled or exceeded Lancota in grain protein content. Grain yields ranged from 35.6 to 42.3 q/ha compared with 36.5 q/ha for Bezostaya 1. Plant height of the lines was from 90 to 103 cm compared with 95 and 110 cm for Bezostaya 1 and Lancota, respectively.

The eight populations discussed performed well at multiple

University of Nebraska-Lincoln and USDA/SEA-AR

sites in 1976 and again in 1977. There was excellent expression of the elevated-protein trait in the populations which together with their intermediate plant height and apparent yield potential, should make them useful as improved germplasm for breeders.

The "high protein-high lysine" (HP-HL) wheat observation nursery was organized in 1974 by the Nebraska Agricultural Experiment Station and the Science and Education Administration, U.S. Department of Agriculture, under a contract with the Agency for International Development, U.S. Department of State.

Primary objectives of this nursery are to: 1) provide breeders and cooperators with improved germplasm for elevated levels of grain protein and/or lysine; 2) test the degree of expression of the high protein and high lysine traits in a diverse array of environments; and 3) test the interactions of agronomic characteristics with the grain quality traits.

Numerous spring X winter wheat crosses have been made at Lincoln, Nebraska, in an attempt to combine genes for high protein and/or lysine which have been found in each type (Vogel et. al., 1973). Resulting lines are classified for growth habit and assigned either to the spring wheat or winter wheat sections of the HP-HL nursery.

Experimental lines selected for inclusion in this nursery possess elevated levels of grain protein, lysine (% of protein), or combinations of these traits based on preliminary laboratory evaluation at Lincoln, Nebraska. In addition, selection has been aimed toward increased yield potential, shorter straw, and improved head type.

The data presented and discussed in this report are derived from the second and third HP-HL winter wheat observation nurseries grown in 1976 and 1977, respectively. The number of entries in each nursery are given below:

Year	Number of entries	Description of entries
1976	402	382 lines plus (4 check varieties X 5 reps)
1977	196	176 lines plus (4 check varieties X 5 reps)

The check varieties were Bezostaya 1, Centurk, CI13449, and Lancota. Bezostaya 1 has excellent yield potential and broad adaptation. Centurk possesses excellent winterhardiness and good yield potential. CI13449 was used as a high lysine check, while Lancota was included because of its elevated grain protein.

The 1976 nursery was sent to 26 locations in 17 countries; the 1977 nursery to 32 locations in 22 countries. The locations from which yield data and grain quality data were available for all entries are shown below:

Location	Year 1976	Year 1977
Argentina, Bordenave	X	X
Iran, Karaj	X	X
Iraq, Sulaimaniya		X
Korea, Suwon	X	
South Africa, Bethlehem	X	X
Turkey, Erzurum	X	X
Turkey, Eskisehir	X	
USA, Stillwater, Oklahoma	X	X
	7 sites	6 sites

The nursery consisted of only one replication at each site; consequently the data are more "observational" than "designed". The locations were used as replications in a standard RCB design for the statistical analyses. A subsequent lack of precision in measuring environmental variation was noted for grain yield since the LSD and CV values were large. The grain protein and lysine data analyses appeared to have adequate precision without replication of plots, however.

The 1977 nursery contained only a few lines from the 1976 nursery. This was to facilitate movement of new germplasm into the nursery. A preliminary analysis of the 1976 HP-HL nursery was performed on data from replicated plots grown at Yuma, Arizona. Lines which performed exceptionally well in the replicated trial were carried over into the 1977 nursery.

The results of the 1976 and 1977 nurseries can be seen for seven selected populations along with the check varieties in Tables 1 and 2. Table 1 shows the mean values obtained in the Yuma, Arizona, experiment which had four replications. The 1977 nursery had both higher yields and higher protein values than the 1976 experiment.

The seven populations compared more favorably in yield with Bezostaya 1 in 1977 than in 1976. Protein values of the experimentals exceeded those of the checks in both years.

Table 1. Mean values of grain protein, lysine, and agronomic characters for selected experimental lines and check varieties evaluated in replicated plots in the Second and Third High Protein-High Lysine Winter Wheat Observation Nurseries at Yuma, Arizona, USA, in 1976 and 1977, respectively.

Variety	N	Grain yield		Grain protein		Lysine (% of protein)		Plant height
		1976	1977	1976	1977	1976	1977	1977
		q/ha		%		%		cm
NB 66403/5/NB 69581/4/NB 69565/3/ Jing Kwang/2/Atl 66/Cmn	3	44.5	45.1	14.5	18.1	3.0	2.8	119
NE 7060	10	43.9	44.4	14.7	18.1	3.0	2.9	122
Sava//Purdue 4930/NB 69655	2	43.3	50.1	14.4	18.1	3.0	2.8	128
ID 0033/Purdue 4930//Moldova	4	31.6	54.6	14.2	17.3	3.1	2.8	104
Rannaya 12/Bezostaya 4	3	42.9	50.9	14.7	17.5	2.9	2.6	116
Atl 66/Cmn//Unknown	2	39.9	49.1	13.5	17.2	3.1	3.0	124
Rannaya/Lovrin 13	5	39.6	52.3	14.3	17.0	3.1	2.8	117
Lancota	5	43.5	46.2	13.4	16.4	3.1	2.7	136
Bezostaya 1	5	46.6	45.8	13.4	16.8	3.0	2.7	120
Centurk	5	47.5	53.1	12.2	15.2	3.2	2.9	127
CI 13449	5	42.9	40.2	13.0	15.1	3.3	2.7	94
Nursery mean (all entries)		41.3	48.1	13.9	16.8	3.1	2.8	120
Associated L.S.D. (.05)		8.5	10.6	0.9	--	0.2	---	8
Nursery C.V. (%)		14.9	15.9	4.7	--	3.6	---	4.9

Table 2 lists the mean values of the seven experimental populations and check varieties averaged over 7 and 6 sites for the 1976 and 1977 experiments, respectively.

The results were similar in the two years. Yields of the experimental populations were essentially equal to that of Bezostaya 1. Along with excellent yield potential, these populations also possess higher grain protein than Bezostaya 1. Lysine differences were small, and ranged only from 2.7 to 3.2%.

Plant height was consistent over the two years. CI13449 was the shortest variety and Lancota was the tallest variety in the experiments. The seven experimental populations were comparable with Bezostaya 1 in plant height.

Two-year mean values for agronomic and grain quality traits appear in Table 3. The two-year means for grain yield, protein content, and lysine content averaged over the international sites compare well with those obtained from the replicated nurseries at Yuma, Arizona.

Correlation coefficients of grain protein with other traits are shown in Table 4. The relationship of yield with protein content was negative and statistically significant for only three of the seven populations in 1976. Bezostaya 1 and the overall nursery also had negative significant "r" values. In 1977, none of the correlation coefficients of yield with protein were statistically significant.

Plant height was significantly negatively related to protein content for all experimental populations and check varieties in 1976; however, in 1977 only CI13449 showed a statistically significant relationship.

Only one population, Rannaya 12/Bezostaya 4, failed to show a negative statistically significant relationship between grain protein content and lysine (% of protein) in 1976. In 1977, four of the seven populations had non-significant correlation coefficients.

A regression technique, used to adjust lysine values to a common protein level, reduces the bias in lysine levels caused by fluctuations in protein content. The subsequent adjusted lysine values generally have less variation. The correlation coefficients of protein with adjusted lysine were less than the coefficients of protein with non-adjusted lysine values for most populations and checks.

Table 5 contains the correlation coefficients of grain yield with plant height and date of flowering. The 1976 nursery displayed many statistically significant comparisons. Taller wheats tended to yield more than shorter types, and early lines generally yielded more than later types.

Table 2. Mean values of grain protein, lysine, and agronomic characters for selected experimental lines and check varieties evaluated over multiple sites in the Second and Third High Protein-High Lysine Winter Wheat Observation Nurseries in 1976 and 1977, respectively.

Variety	N	Grain yield		Grain protein		Lysine (% of protein)		Plant height	
		1976	1977	1976	1977	1976	1977	1976	1977
		q/ha		%		%		cm	
NB 66403/5/NB 69581/4/NB 69565/3/ Jing Kwang/2/Atl 66/Cmn	3	43.4	36.8	16.7	16.7	2.8	2.7	94	96
NE 7060	10	44.2	37.5	16.6	16.3	2.8	2.8	93	94
Sava//Purdue 4930/NB 69655	2	42.0	38.3	16.0	16.1	3.0	3.0	96	102
ID 0033/Purdue 4930//Moldova	4	39.1	39.0	16.6	15.5	2.8	3.0	97	90
Rannaya 12/Bezostaya 4	3	44.6	36.4	15.7	15.9	2.7	2.7	92	90
Atl 66/Cmn//Unknown	2	44.3	42.3	15.7	15.0	2.8	2.9	94	96
Rannaya/Lovrin 13	5	43.4	36.8	15.0	15.4	2.8	2.8	95	94
Lancota	5	48.9	41.4	14.4	15.1	2.8	2.8	107	110
Bezostaya 1	5	44.4	36.5	14.2	14.3	2.8	2.8	94	95
Centurk	5	48.9	39.3	13.1	13.1	3.0	3.0	101	103
CI 13449	5	32.3	28.4	12.4	12.9	3.2	3.2	90	81
Nursery mean (all entries)		42.1	36.3	15.1	15.0	2.8	2.9	100	97
Associated L.S.D. (.05)		8.4	8.5	1.0	1.2	0.1	0.2	7	7
Nursery C.V. (%)		19.0	20.6	6.6	7.1	4.9	6.1	6.6	6.4

Table 3. Two-year mean values of grain yield, protein content, lysine content, and plant height for selected populations and check varieties in the High Protein-High Lysine Winter Wheat Observation Nursery, 1976 and 1977.

Variety	N	Grain yield (q/ha)		Grain protein (%)		Lysine (% of protein)		Plant height (cm)
		Intl[a] sites	Yuma,[b] Arizona	Intl[a] sites	Yuma,[b] Arizona	Intl[a] sites	Yuma,[b] Arizona	Intl[a] sites
NB 66403/5/NB 69581/4/NB 69565 /3/Jing Kwang/2/Atl 66/Cmn	3	40.1	44.8	16.7	16.3	2.8	2.9	95
NE 7060	10	40.9	44.2	16.5	16.4	2.8	3.0	94
Sava//Purdue 4930/NB 69655	2	40.2	46.7	16.1	16.3	3.0	2.9	99
ID 0033/Purdue 4930//Moldova	4	39.1	43.1	16.1	15.8	2.9	3.0	94
Rannaya 12/Bezostaya 4	3	40.5	46.9	15.8	16.1	2.7	2.8	91
Atl 66/Cmn//Unknown	2	43.3	44.5	15.4	15.4	2.9	3.1	95
Rannaya/Lovrin 13	5	40.1	46.0	15.2	15.7	2.8	3.0	95
Lancota	5	45.2	4[illegible].9	14.8	14.9	2.8	2.9	109
Bezostaya 1	5	40.5	46.2	14.3	15.1	2.8	2.9	95
Centurk	5	44.1	50.3	13.1	13.7	3.0	3.1	102
CI 13449	5	30.4	41.6	12.7	14.1	3.2	3.0	81

a/ Mean values over 7 sites in 1976 and 6 sites in 1977.

b/ The Arizona nursery had 4 replications in each year.

Table 4. Correlation coefficients of grain protein content with grain yield, plant height, and lysine for selected populations and check varieties in the High Protein-High Lysine Winter Wheat Observation Nursery, 1976 and 1977.

Variety	Number of paired comparisons		Grain protein vs. Grain yield		Grain protein vs. Plant height		Grain protein vs. Lysine/protein		Grain protein vs. Adjusted lysine/protein	
	1976	1977	1976	1977	1976	1977	1976	1977	1976	1977
NB 66403/5/NB 69581/4/NB 69565 /3/Jing Kwang/2/Atl 66/Cmn	21	18	-.75**	.04	-.46*	.10	-.52*	-.12	-.57**	-.11
NE 7060	70	60	-.56**	-.02	-.44**	-.07	-.46**	-.33**	-.35**	.03
Sava//Purdue 4930/NB 69655	14	12	-.02	.40	-.56*	-.14	-.66**	-.61*	-.37	-.44
ID 0033/Purdue 4930//Moldova	28	24	-.33	-.12	-.38*	-.06	-.40*	-.13	-.39*	.11
Rannaya 12/Bezostaya 4	21	18	-.48*	-.06	-.65**	-.32	-.34	-.07	-.23	.30
Atl 66/Cmn//Unknown	14	12	-.28	.29	-.66**	.19	-.67**	-.75**	-.64*	-.52
Rannaya/Lovrin 13	35	30	-.24	-.03	-.52**	-.07	-.70**	-.05	-.54**	.31
Lancota	35	30	-.28	-.02	-.53**	-.15	-.56**	-.47**	-.15	.10
Bezostaya 1	35	30	-.36*	.16	-.58**	-.01	-.57**	-.43*	-.28	.27
Centurk	35	30	.04	.13	-.48*	-.16	-.80**	-.70**	-.35*	.13
CI 13449	35	30	-.06	-.31	-.44**	-.40*	-.79**	-.47**	.14	.51**
Overall Nursery	2814	1176	-.29**	-.04	-.45**	-.13**	-.68**	-.46**	-.41**	-.03

* Significant at the .05 level.

** Significant at the .01 level.

Table 5. Correlation coefficients of grain yield with plant height and date of flowering for selected populations and check varieties in the High Protein-High Lysine Winter Wheat Observation Nursery, 1976 and 1977.

Variety	Number of paired comparisons		Grain yield vs.			
			Plant height		Date of flowering	
	1976	1977	1976	1977	1976	1977
NB 66403/5/NB 69581/4/NB 69565/3/ Jing Kwang/2/Atl 66/Cmn	21	18	.46*	.34	-.71**	-.49
NE 7060	70	60	.51**	.14	-.60**	-.33*
Sava//Purdue 4930/NB 69655	14	12	.63*	.01	-.65*	-.11
ID 0033/Purdue 4930//Moldova	28	24	.42*	-.04	-.57**	-.11
Rannaya 12/Bezostaya 4	21	18	.69**	.21	-.69**	-.20
Atl 66/Cmn//Unknown	14	12	.64*	.46	-.75*	-.51
Rannaya/Lovrin 13	35	30	.47**	-.09	-.45*	-.41*
Lancota	35	30	.42*	-.41*	-.53**	-.40*
Bezostaya 1	35	30	.56**	-.05	-.65**	-.36
Centurk	35	30	.37*	-.30	-.67**	-.43*
CI 13449	35	30	.29	.14	-.77**	.10
Overall Nursery	2814	1175	.45**	.03	-.65**	-.19**

* Significant at the .05 level.

** Significant at the .01 level.

Much of these apparent trends are probably due to environmental effects, however. Higher fertility and better moisture conditions at sites would be expected to cause the wheats to grow taller and yield more, thus accounting for the uniformly high "r" values for all lines and check varieties. Poor yields at a site where maturity was late would have caused the data to correlate high yields with earliness.

The strongly expressed relationship between yield and plant height in the 1976 experiment was not repeated in the 1977 experiment. The yield-flowering date relationship was negative in 1977, but the magnitude of the correlation coefficients was much reduced from those computed in 1976.

Figures 1 and 2 show the relationships between grain protein content and grain yield for the entries in the 1976 and 1977 nurseries, respectively. The seven selected populations and check varieties are identified. Unidentified entries are denoted with dots.

Yield were notably lower in 1977 than in 1976, but the protein levels were essentially equal. The selected populations appear to be as productive as Bezostaya 1 and they have a distinct advantage in protein content over the check varieties.

The NE7060 lines occupy the same relative positions in both Figures 1 and 2. They are attractive, medium statured wheats with excellent head type and seed quality. One NE7060 selection was included in the IWWPN for evaluation in 1979 and 1980.

Figures 3 and 4 display the relationship of lysine (% of protein) to total grain protein. The relationship was defined as negative and curvilinear by Vogel (1973), and Johnson et al. (1974). That type of relationship can be seen in these figures as well.

It should be noted, however, that, while the selected populations had higher protein levels than the check varieties, they contained essentially the same proportion of lysine in their protein as Bezostaya 1 and Lancota. The two selections of Sava// Purdue 4930/NB69655 had excellent combinations of high protein and high lysine levels in both 1976 and 1977.

The worth of the selected populations can be assessed by comparing their production of grain, protein, and lysine per unit area. The two-year means from Table 3 were used to calculate the per hectare production figures which follow.

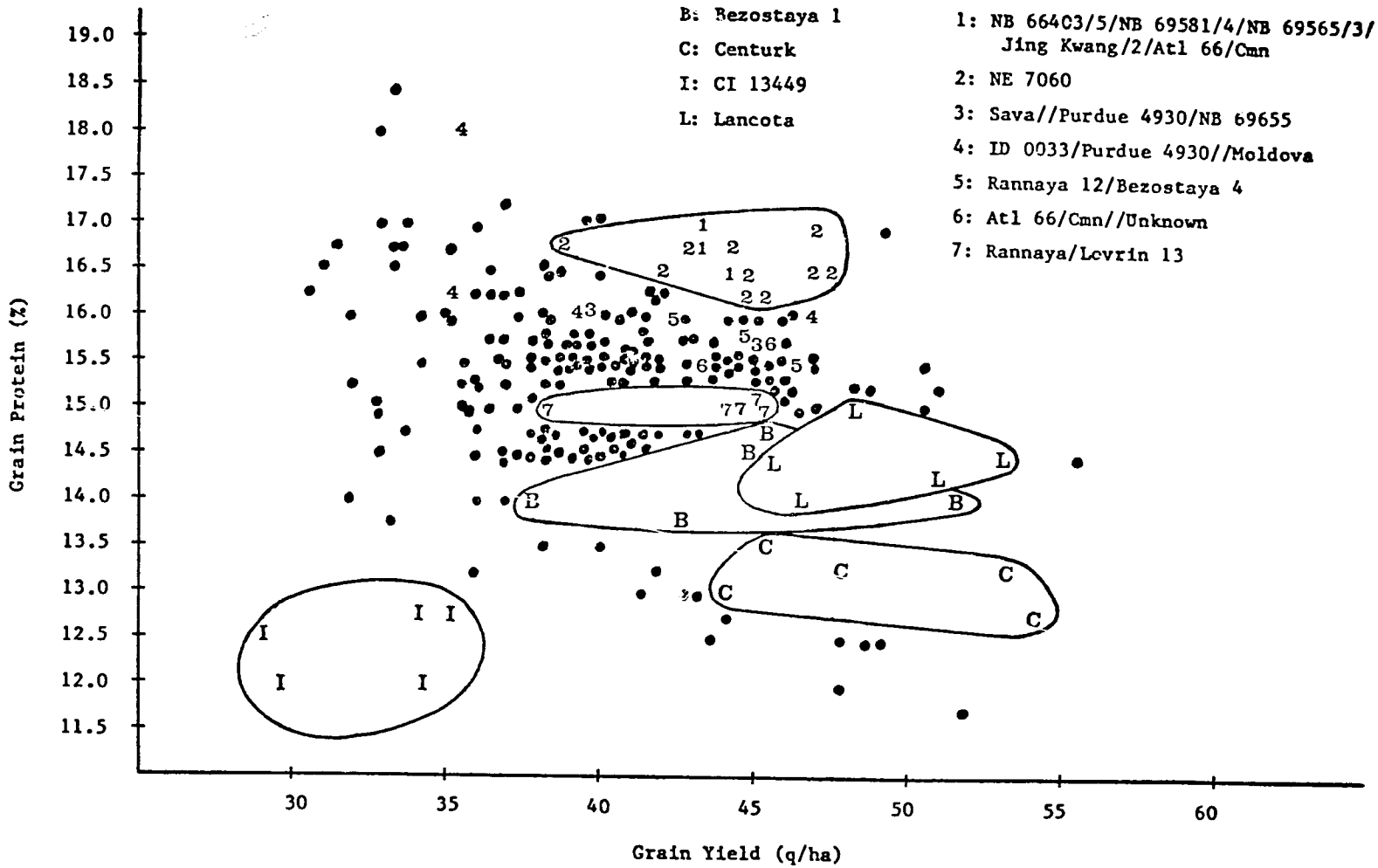

Figure 1. Grain protein content versus grain yield for entries in the second high protein-high lysine winter wheat observation nursery averaged over seven sites in 1976.

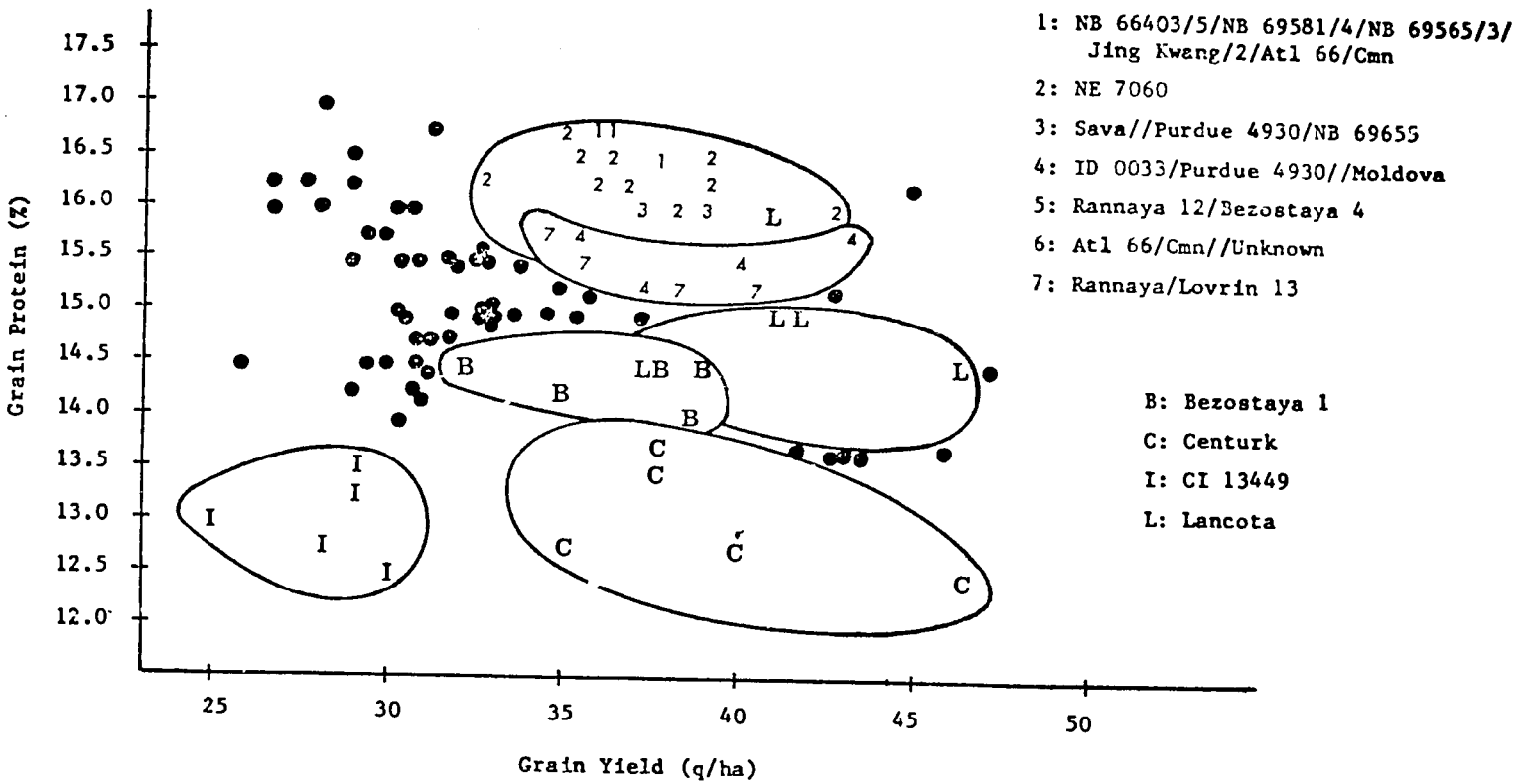

Figure 2. Grain protein content versus grain yield for entries in the third high protein-high lysine winter wheat observation nursery averaged over six sites in 1977.

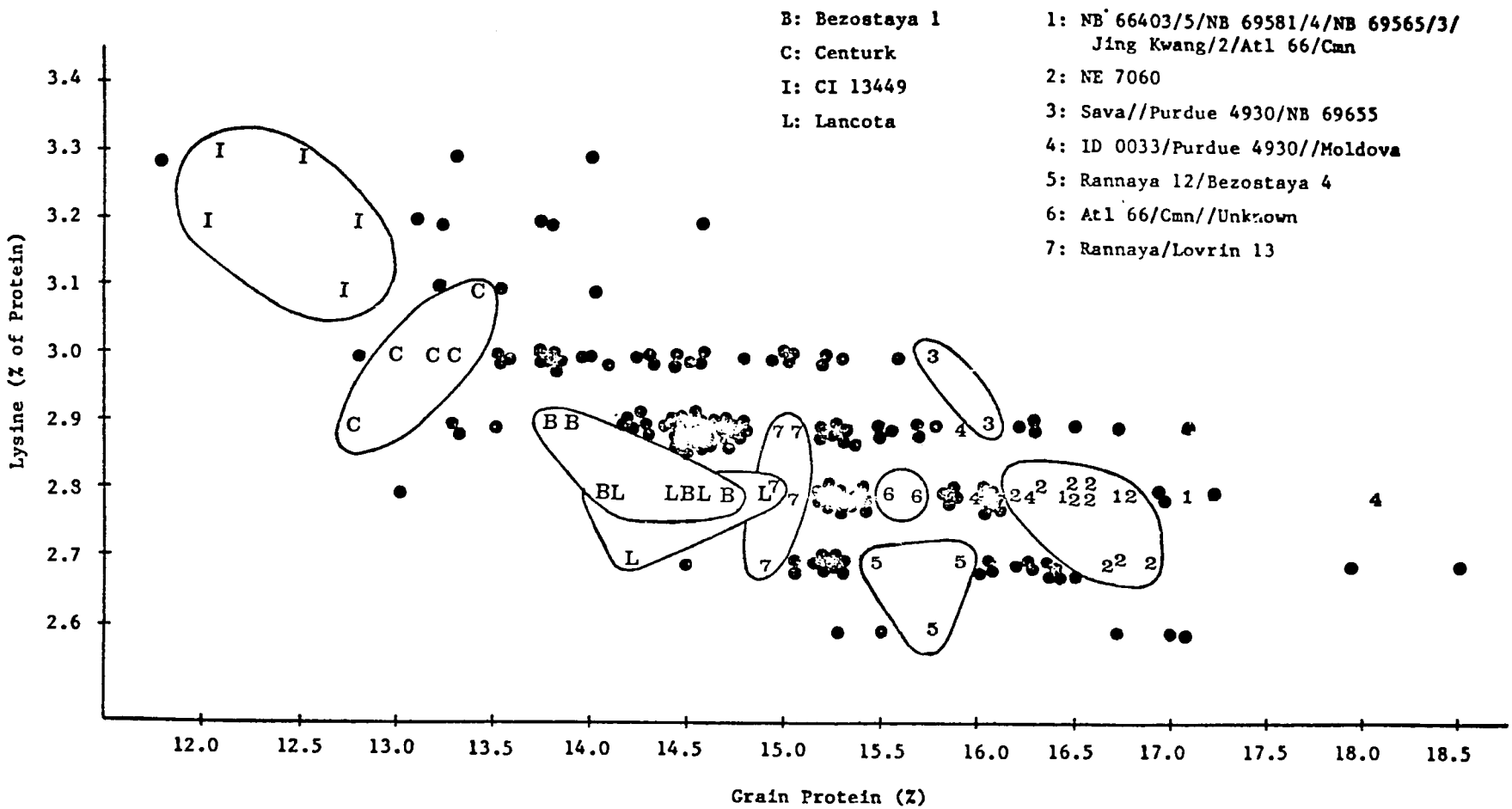

Figure 3. Lysine (% of protein) versus grain protein content for entries in the second high protein-high lysine winter wheat observation nursery averaged over seven sites in 1976.

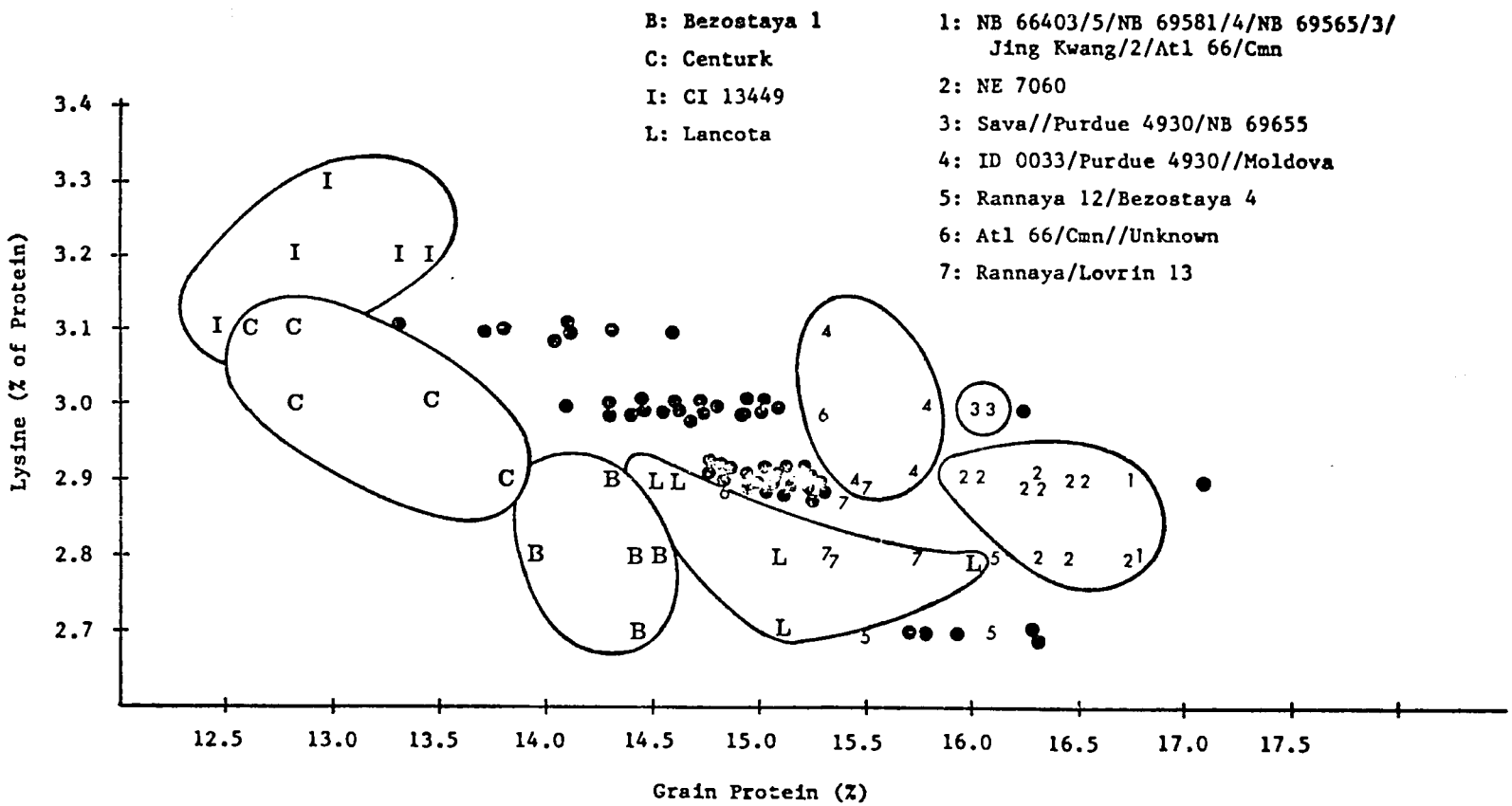

Figure 4. Lysine (% of protein) versus grain protein content for entries in the third high protein-high lysine winter wheat observation nursery averaged over six sites in 1977.

Variety	Production per hectare (kg)		
	Grain	Protein	Lysine
NB66403/5/NB69581/4/NB69565/3/ Jing Kwang/2/Atl 66/Cmn	4010	670	18.8
NE7060	4090	675	18.9
Sava//Purdue 4930/NB69655	4020	647	19.4
ID 0033/Purdue 4930//Moldova	3910	630	18.3
Rannaya 12/Bezostaya 4	4050	640	17.3
Atl 66/Cmn//Unknown	4330	667	19.3
Rannaya/Lovrin 13	4010	610	17.1
Lancota	4520	669	18.7
Bezostaya 1	4050	579	16.2
Centurk	4410	578	17.3
CI13449	3040	386	12.4

Lancota, because of its high grain yield, also produced a high amount of protein and lysine per hectare. The NE7060 population led the group in total protein produced per hectare. All of the selected populations produced more protein per hectare than Centurk and Bezostaya 1.

Four of the populations narrowly exceeded the amount of lysine production recorded for Lancota. The highest value, calculated for the Sava//Purdue 4930/NB69655 selections, was 3.2 kg more than the value for Bezostaya 1. Although CI13449 was the high lysine check, its lower grain yield, and low protein content led to notably low lysine production per hectare.

Summary

High protein and/or high lysine wheat selections have been distributed to cooperators at various international test sites for observational purposes since 1974 by the University of Nebraska.

Results from the 1976 and 1977 nurseries were examined to find those selections which combined good yield potential with high protein and/or lysine. A number of lines were observed which performed well in both years. These lines comprised seven populations.

The populations were compared with four check varieties, averaged over 7 and 6 international test sites from the 1976 and 1977 nurseries, respectively. The populations compared favorably with Bezostaya 1 in grain yield. They possessed high grain protein content and produced more total protein per hectare than either Centurk or Bezostaya 1.

The experimental selections should have value as germplasm for breeders seeking to increase total protein production per hectare.

References

Johnson, V. A., P. J. Mattern, J. E. Stroike, and K. D. Wilhelmi. 1975. Breeding for improved nutritional quality in wheat. In Proc. of the 2nd Int'l. Winter Wheat Conf., Zagreb, Yugoslavia. p. 316-333.

Kuhr, S. L., K. D. Wilhelmi, V. A. Johnson, and P. J. Mattern. 1980. Results of the second high protein-high lysine wheat observation nursery grown in 1976. Nebr. Res. Bul. 291. 196 p.

Kuhr, S. L., V. A. Johnson, P. J. Mattern, and K. D. Wilhelmi. Results of the third high protein-high lysine wheat observation nursery grown in 1977. (in preparation)

Vogel, K. P., V. A. Johnson, and P. J. Mattern. 1973. Results of systematic analyses for protein and lysine composition of common wheats (Triticum aestivum L.) in the world collection. Nebr. Res. Bul. 258. 27 p.

DEVELOPMENT, SCOPE, AND GENETIC POTENTIAL OF INTERNATIONAL NURSERIES IN BREEDING PROGRAMS

R. A. Kilpatrick, J. G. Moseman, and W. M. Porter
United States

Abstract

The U. S. Department of Agriculture's wheat mildew nursery program is summarized for 1950-1978. The 29 nurseries, comprising 1,376 entries were tested at 70 locations in 27 countries and 29 states within the United States. Four selections ('Asosan', 'Khapli', 'Yuma', and Wisconsin Sel. C.I. 12632) remained highly resistant (a disease coefficient ADC of 5.0 or less based on 0 to 99) for periods of 10 to 17 years before exhibiting symptoms of susceptibility. Seed of 37 entries selected as an elite set of mildew resistance germplasm will be available for distribution in 1981.

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The U. S. Department of Agriculture's cereal disease testing program began in 1918, when wheat (Triticum spp.) nurseries were established at 10 locations within the U. S. (4). The objectives of this early program were to test advanced lines and selections; to determine pathogenicity; to study sources of resistance; and to study changes in the rust populations. This early nursery program was known as the Uniform wheat rust nursery. In 1932 the nursery material was separated according to growth habit. The program has since been known as the Uniform spring or Uniform winter wheat rust nursery. The success of this program led to the development of the International spring wheat rust nursery and Uniform wheat mildew nursery in 1950. The International winter wheat rust nursery was started in 1955, the International winter and spring wheat stripe rust nurseries in the 1960's and the spring and winter wheat mildew nurseries in the 1970's. The planting of special nurseries in different locations was shown to be an effective technique for evaluating the reaction of cultivars and selections to different populations of disease producing organisms. In addition, regional testing prevented introducing foreign pathogens in new areas. With the exception of the stripe rust nurseries, which were dropped from the program in 1977, the two international wheat rust nurseries are continued today. Detailed information on the rust nurseries has been published previously (2,3,4,5). In this paper, we will describe primarily the spring and winter wheat mildew nurseries, although references will be made to the International rust nurseries for comparative purposes.

Plant Genetics and Germplasm Institute, SEA-AR, U. S. Department of Agriculture, Beltsville, Maryland 20705.

Objectives of the rust and mildew programs include: 1) evaluating advanced selections and cultivars for their reaction to the pathogen populations around the world; 2) monitoring changes in virulence within those populations; 3) identifying new sources of host resistance, and 4) determining effectiveness of genes.

The wheat mildew nursery program has involved many people since it began in 1950. Within the U. S. Department of Agriculture, the coordinators have been C. V. Lother, H. R. Powers, Jr., L. W. Briggle, A. L. Scharen, J. G. Moseman, and R. A. Kilpatrick. Appreciation is expressed to all for their contribution.

Collaborators have been located at universities, experiment stations, and Federal agencies in Argentina, Australia, Austria, Belgium, Bulgaria, Canada, Chile, Czechoslavakia, Denmark, England, France, Greece, India, Israel, Italy, Japan, Nepal, Netherlands, New Zealand, Paraguay, Republic of South Africa, Romania, Sweden, Turkey, United States (Alabama, Arkansas, Colorado, Connecticut, Florida, Georgia, Idaho, Illinois, Indiana, Kentucky, Louisiana, Maryland, Massachusetts, Michigan, Mississippi, Montana, New Jersey, New York, North Carolina, Ohio, Pennsylvania, South Carolina, Tennessee, Texas, Utah, Virginia, Washington, West Virginia, and Wisconsin), and Yugoslavia. Other locations have grown elite materials for germplasm. In 1978, the nurseries were sent to 68 locations in 22 countries and 26 states.

The selections within the nurseries have been wheat and wheat relatives representing a diverse spectrum of germplasm. The number of entries per nursery and number of sets prepared has remained about the same for the past three years (Table 1). There has been a gradual increase in number of countries submitting seed. Since 1960, collaborators at 70 locations in 27 different countries and 29 states within the U. S. have planted the nurseries, recorded notes and returned data. The number of people returning winter wheat data has been slightly more than that returning spring wheat data. At least 85 percent of the 1,376 entries tested since 1950 have had Cereal Identification or Plant Introduction numbers and were a part of the U. S. Department of Agriculture's Small Grains Collection at Beltsville. Between 1950 and 1960 all entries in the nurseries had a C.I. or P.I. number.

The rust nurseries have been larger than the mildew nurseries (Table 2). The spring wheat nursery has been composed of a greater diversity of germplasm than the winter wheat nursery. The percentage of data sheets returned has fluctuated from 60 to 70 for both nurseries while the percentage of data sheets returned for the mildew nurseries has been lower.

A standard susceptible check was included in each nursery to serve as a spreader row and to provide a guide of disease severity throughout the nursery. Cultivars included as susceptible checks have been Carala, Purple Straw, Little Club, Vermillion, Seneca, Lemhi, Washington State No. 4, Gaines, Mentana,

Table 1. Statistics of the Wheat Mildew Programs

	Year							
	1977		1978		1979		1980	
	Spring	Winter	S	W	S	W	S	W
No. of Entries	100	86	109	70	140	40	110	88
Origin of New Entries								
Countries	5	7	4	7	12	1	19	17
States	2	6	3	1	4	2	9	16
No. of Boxes Sent	56	64	53	64	46	64	46	62
Location of Nurseries	49	56	49	63	47	64	46	62
Countries	17	17	20	21	20	19	20	18
States	13	15	10	18	11	18	11	18
Data Sheets Returned	24	46	27	46	23	47	--	--

Table 2. Statistics of International Rust Nurseries

	1976		1977		1978		1979		1980	
	S[a]	W	S	W	S	W	S	W	S	W
No. of Entries	720	260	656	450	424	400	540	180	420	170
Sources of Seed										
Countries	35	22	43	19	32	29	35	13	41	24
States	16	24	15	19	13	22	9	15	13	24
No. of Boxes sent	57	42	53	40	64	48	63	48	64	43
Countries	33	22	32	21	31	22	31	22	31	20
Data Returned	37	26	35	26	44	29	--	--	--	--

[a] S = spring material; W = winter material

Omar, Chancellor, and Paha. Entries were separated for growth habit (spring or winter) in 1974. 'Washington State No. 4' has been used as the susceptible standard in the winter nursery; 'Lemhi' has been the susceptible check in the spring nursery. The highest rating given entries in the nurseries was usually the susceptible checks. The ADC of the checks fluctuated from 36 to 74, averaging 62 percent infection.

Evaluation of entries was made in the field for each of the years. Readings at all locations were based on percentage of individual plants infected within a row or hill on a basis of '0' = no disease to '99' = severe disease. An ADC was calculated for each entry from all locations for comparative purposes. The ADC was calculated by adding the readings (disease severity) and dividing by the total number of locations submitting data. This provided a value of 0 to 99. Since 1950, 32 percent of the entries have had an ADC of 5 or less in one or more years. The selections ('Asosan', 'Khapli', 'Yuma', and Wisconsin Sel. CI 12632) were in the nursery for 10 to 17 years before reaching an ADC of 5 or more. Fourteen entries had been in the nursery for two or more years and had an ADC of 5 or less. Resistant cultivars remained in the nursery for an average of 3.3 years before reaching an ADC of 5 or more, indicating potential susceptibility.

Varietal differences in susceptibility were noted within and between countries. In 1951, encouraging mildew wheat selections were planted in Norway. A difference in rating was also given selections grown in Yugoslavia and Italy; in the Netherlands, and Sweden and England. New biotypes have been detected by growing these nurseries in India and Czechoslovakia. Within the U. S. the reaction of near monogene lines has varied within and between States.

Breeding for powdery mildew resistance has been a major objective of many programs around the world. These included locations in Georgia, North and South Carolina, Maryland, Sweden, Austria, England, Yugoslavia, Italy, and others. Outstanding cultivars have been developed by personnel from the above locations. In 1957, Powers (personal communications) reported that the cultivar 'Normandie' had two genes controlling resistance to mildew. It suggests that multigenic resistance may account for the longevity of the low ADC. Other cultivars ('Asosan', 'Khapli', Wis. 245, 'Yuma', M1, 0224/52 and CI 126232) may have more than one gene controlling resistance to mildew.

Briggle (1) developed near-isogenic lines of wheat for resistance to powdery mildew and identified genes controlling resistance in the different lines (Table 3). McIntosh (6) has continued the program of gene identification and mapping of chromosomes in cultivars of wheat. Many of these parents and near-isogenic lines have been included in this program. The reaction of parents and/or near-isogenic lines indicate that selections containing the allele for resistance to Ml 1, Ml 3a, and Ml 4 were the most effective genes for controlling powdery mildew in wheat.

Table 3. Average Disease Coefficients of Near-Isolines for Three Years.

Near-Isoline	Gene	Year- Coef. 1973	1978	1979	Avg. Coef.
Axminister/8CC	1	11	12	9	10.1
Norka/8CC	1	13	12	8	9.7
Ulka/8CC	2	18	36	38	27.4
Asosan/8CC	3a	8	11	21	10.1
Chul/8CC	3b	10	10	7	7.4
Sonora/8CC	3c	6	13	12	9.0
Khapli/8CC	4	8	17	22	13.7
Yuma/8CC	4	9	17	20	13.0
Avg. Coef.		10.4	16	17.1	12.6

The data suggest that a gene for virulence to Ml 3a and Ml 4 in the mildew population is building up and should be watched. The value of working with near-isogenic lines of wheat has been demonstrated for leaf rust by Smith and Kilpatrick (7). A manuscript is being prepared on the effectiveness of genes for controlling powdery mildew in wheat.

An elite set of 37 lines that have had an ADC of 5 or less for two or more years in this program is being prepared. Seed will be increased and distributed upon request in 1980-81.

Literature Cited

1. Briggle, L. W. 1969. Near-isogenic lines of wheat with genes for resistance to *Erysiphe graminis* f. sp. *tritici*. Crop Sci. 9:70-72.
2. Kilpatrick, R. A. 1971. International rust nurseries -- a special article. IBP Aerobiology Newsletter 4:3-5.
3. Kilpatrick, R. A., L. P. Reitz, and F. A. Jimenez. 1972. Cereal rust nurseries in the Caribbean area, 1950-72. U. S. Dept. Agric. ARS-NE-3, p. 14.
4. Kilpatrick, R. A., and J. G. Moseman. 1979. Fifty years of national and international cereal disease testing. Proc. 5th Int. Wheat Genet. Symp., pp. 143-148. New Delhi, India.
5. Loegering, W. Q., and N. E. Borlaug. 1963. Contributions of international spring wheat rust nursery to human progress and international good will. U. S. Dept. Agric. ARS-34-46, p. 8.
6. McIntosh, R. A. 1979. Catalogue of gene symbols for wheat, 1979 supplement. Cereal Res. Comm. 7:61-64.
7. Smith, R. T., and R. A. Kilpatrick. 1978. Effectiveness of genes for leaf rust resistance in international wheat rust nurseries, 1970-1975. EUPHYTICA 27:511-519.

REPORTING THE RESULTS CONCERNING THE AGRONOMIC QUALITIES OF WHEAT VARIETIES FROM THE IWWPN.

I. Govedarov, L. Todorov, A. Tzenov, V. Gotzova, and Ts. Rachinsky
Bulgaria

Abstract

Results of the evaluation of IWWPN wheat varieties for the period of 1977-1979 under the conditions of the Institute for Wheat and Sunflower near the town of Tolbukhin are summarized.

Best average productivity for the period of 1977-1979 was manifested by the Bulgarian variety Jubiley (2109-36) and the Yugoslavian varieties Zg 4270/73, Zg 887/73, Zg 4364/73, and Zg 4293/73. Good productivity also was shown by Sadovo 1 (Bulgaria) and F 53-70 (Romania). The variety Jubiley has very good winterhardiness, short stem, resistance to brown rust, and good ecological plasticity. These qualities placed Jubiley at the head of the list for the two years mentioned as the highest yielding variety from all the trials in the IWWPN system. Yugoslavian varieties have low resistance to lodging, complex resistance to brown rust, stem rust and powdery mildew, but possess comparatively low winterhardiness.

From all varieties tested in 1978-1979, high yield potential was manifested by NR 72/837 (Austria), Slavia (Czechoslovakia), Partizanka (Yugoslavia), and Slavyanka (Bulgaria). In addition NR 72/837 possesses very good winterhardiness, resistance to brown rust and powdery mildew, and a relatively short stem. Partizanka and Slavyanka have good resistance to brown rust and lodging.

On the basis of complex evaluation of the biochemical and the technological properties of the grain, we have concluded that F 53-70, Jubiley, Slavyanka, and Partizanka are of the high quality class of Bezostaya 1.

Breeding of winter common wheat in recent years has developed new intensive varieties of potential productivity up to 80-100 q/ha with short and strong stems, good winterhardiness, resistance to lodging, and good bread quality. The study of varieties included in the International Winter Wheat Performance Nursery (IWWPN) makes it possible to estimate the progress achieved in the separate countries (1, 2, 3, 6, 7, 8).

In the period 1977-1979, 30 wheat varieties were tested at the Institute for Wheat and Sunflower near G. Toshevo, Bulgaria. On the basis of the results obtained valuable conclusions can be drawn about the production-type bread wheats grown in regions of

Institute for Wheat, Tolbukhin

about 500 mm rainfall. Annually, half of the varieties in the IWWPN are grown for a first year; the other half for a second one, according to the method followed by Nebraska, USA (1, 6).

The autumn and winter of 1976-1977 were accompanied by favorable climatic conditions that contributed to the good development and winter survival of the plants of all varieties, even though minimum temperatures in January dropped to -16°C. Rainfall during the vegetation period was 521.7 mm, i.e., close to the average over years. Some of the varieties were attacked by powdery mildew and brown rust as early as winter. Later the infection grew even higher. The rainfall and the high temperatures in May and June resulted in lodging of some varieties, while some of the earlier ones ripened prematurely. Sowing in the autumn of 1977 was characterized for late and nonuniform emergence and slow growth. In spring the retarded growth of plants was overcome. The heavy rainfall in May (74.4 ml/m^2) and in June (73.4 ml/m^2) accompanied by strong winds caused lodging of some varieties and attacks of fusariosis and powdery mildew. Due to these, 1000-grain weight and gluten of the dough decreased in the varieties Lindon, Zg 4293/73, Zg 4240/73, Zg 887/73, Ticonderoga, Partizanka, Samson, Disponent, Nap Hal/Atlas 66 and Budifen.

In the autumn of 1978 soil moisture was insufficient. Thus, the nonuniformly emerged plants entered winter at the 2-3 leaf stage. Lack of snow cover and low temperatures towards the middle of January caused frost damage and strong thinning of the stands of varieties with low cold resistance. Rainfall was insufficient in winter and spring as well and some varieties headed too early. In the periods of flowering, filling of the grain and harvesting, high temperature (31.2°C) and heavy rains resulted in comparatively low yields and decreased 1000-grain weight and hectoliter weight.

All tested varieties differed considerably with respect to their cold resistance. Varieties manifesting cold resistance better than that of Bezostaya 1 are Julia, F 54-70, NE73640, Mironovskaya 808, Lindon, Krasnodarskaya 39, while the varieties Sadovo 1, F 53-70, Blueboy, Partizanka and MV-4 are on the level of Bezostaya 1. The varieties Absolvent, CI13449/Centurk, Zg 4240/73, Zg 4364/73, Zg 4293/73, NR 72/837, Slavjanka, Ticonderoga and Newton manifested medium cold-resistance. The rest (Zg 887/73, Slavia, Disponent, Nap Hal/Atlas 66, and Budifen) were of low cold resistance. As the period of grain filling and maturation in 1977/78 were close to the optimum, we have reported the phenological observations of that period (Table 1). Earliest varieties (4 days earlier than Bezostaya 1) are as follows: Zg 4240/73, Zg 887/73, Zg 4364/73, Zg 4293/73, Julia, NE73640, and Newton. Fifteen other varieties ripen 1 to 3 days earlier than Bezostaya 1. The varieties Blueboy, NR 72/857 and Absolvent are on the level of the standard, while Atlas 66 and Disponent are somewhat later varieties (2 and 4 days, respectively). Although conditions in 1977 and 1978 favored lodging of plants, Zg 4240/73, Zg 887/73, Zg 4364/73, Zg 4293/73, Sadovo 1, Julia and Slavia

Table 1. Phenological observations.

Variety	Winter-hardiness+	Ripening, (days)	Height, (cm)	Lodging, (%)	Erys. graminis 1977	Erys. graminis 1978	Erys. graminis 1979	P. recondita 1977	P. recondita 1978
	---------- 1977-78 ----------								
Yubiley	3	138	83	0	5MS	40VS	-	5	tR
Zg 4240/73	3	132	80	0	0	0	-	t	5M
Zg 4364/73	3-	135	83	0	0	0	-	15	10
Zg 887/73	1	132	74	0	0	0	-	25	5R
Zg 4293/73	3+	132	67	0	0	0	-	25	10M
Sadovo 1	4	137	96	0	15MS	90VS	-	100	100VS
F 53-70	4	149	112	25	25MS	25M	-	t	tR
Julia	5	137	102	0	5MS	20MS	-	60	65VS
F 54-70	5	149	110	25	5MS	15MS	-	t	tR
Blueboy	4	140	107	0	50MS	90VS	-	25	25S
Mironovskaya 808	5	142	125	40	5MR	20S	-	60	70VS
Bezostaya 1	4	141	96	40	20MS	40VS	-	60	40S
Lindon	5	138	97	80	15MS	10MS	-	10	tR
Krasnodarskaya 39	5	144	99	25	10MS	50VS	-	100	100VS
NE73640	5	138	99	50	10MS	30VS	-	80	80VS
	---------- 1978-79 ----------								
NR 72/837	4	182	80	0	-	0	tMR	-	5M
Slavia	3.5	176	89	0	-	tR	5MR	-	50MS
Partizanka	4-	183	85	0	-	25MS	40VS	-	5M
Slavyanka	3+	181	98	0	-	35VS	40VS	-	40MS
Martonvasari 4	4+	181	101	5	-	65VS	40VS	-	100VS
Absolvent	4+	183	98	0	-	25VS	40VS	-	50VS
Bezostaya 1	4	183	98	40	-	40VS	65VS	-	40S
Centurk	4+	182	107	80	-	25S	65VS	-	100VS
Ticonderoga	4-	183	84	0	-	tMR	30VS	-	100VS
Samson	3+	180	86	15	-	65VS	40VS	-	100VS
Nap Hal/Atlas 66	3+	181	100	70	-	30VS	65VS	-	tR
Newton	4+	179	88	40	-	40MS	100VS	-	65VS
Disponent	4	185	96	0	-	10M	65VS	-	50MS
Atlas	2	183	116	75	-	15S	40VS	-	0
Budifen	2-	182	92	0	-	25VS	65VS	-	50VS

+ On a scale 0 to 5, 5 = completely resistant.

manifested very high resistance to lodging. Valuable genotypes for short-stem (68-83 cm) are best expressed in the intensive varieties Julia, Zg 887/73, Zg 4240/73 Zg 4364/73 and Zg 4293/73. The feature susceptibility to lodging, is a contradiction between stem height and resistance to lodging. For example, Lindon is of medium stem height but appears to be susceptible to lodging (up to 80%), while Mironovskaya 808 has a long stem (125 cm) but is relatively resistant to lodging.

Resistance and response of varieties to powdery mildew and brown rust have been studied under conditions of natural field infection and to brown rust and stem rust in an artificially infected plot (Table 2). An assessment of the rate of infection (0-100) and the infection type was made also. Yugoslavian varieties Zg 4240/73, Zg 4364/73, Zg 887/73 and Zg 4293/73 showed complete resistance to powdery mildew; the varieties NR 72/837 and Slavia had very high resistance; highly susceptible to powdery mildew are Netwon, Blueboy, and Sadovo 1, having been infected 90-100%. The rest of the varieties were attacked to a different extent and are defined as being moderately resistant or moderately susceptible. Of considerable interest are the results in Table 2 showing resistance to brown rust in the infection plot. Under the conditions of a maximum infection and a large number of races, Yubiley, Zg 4240/73, Zg 887/73, Zg 4293/73, F 53-70, F 54-70, Blueboy, Lindon, Partizanka, Nap Hal/Atlas 66 and Atlas 66 manifested high resistance, and Zg 4364/73, NR 72/837, Slavjanka and Budifen very good resistance. The rest of the varieties were susceptible with the highest infection rate as high as 100 (P average), that being recorded for Sadovo 1, Mironovskaya 808 and other varieties of the second group. The value of P average in NR 73/640, Martonvasari 4, Absolvent, Julia and Bezostaya 1 is lower which is a manifestation of incomplete susceptibility.

The tests with stem rust identified the very high resistance of Zg 4240/73, Zg 4364/73, Zg 887/73, Zg 4293/73, and NE73640 and the good or moderate resistance of Budifen, Newton, and Disponent. All the other varieties were susceptible to the disease. Of particular interest for breeding work are varieties resistant to several diseases. Of all the varieties studied, the Yugoslavian varieties Zg 4240/73, Zg 4364/73, Zg 887/73, and Zg 4293/73 exhibit complex resistance to the three diseases; Nap Hal/Atlas 66 and Budifen are resistant both to brown and stem rust and NR 72/837 to powdery mildew and brown rust.

Grain yields of the varieties tested in 1977 and 1978 give a good indication of their productive potential (Table 3). Highest yield (2-year average) was produced by Yubiley, outyielding Bezostaya 1 by 21.6 q/ha (35.3%). All Yugoslavian varieties studied manifest high productivity too. They outyielded Bezostaya 1 by 15.6-18.2 q/ha (25.5-29.7%) giving at the same time stable yields in both the years of investigation. The high productive potential of Yubiley is due to valuable traits such as short and lodging resistant stems, moderate earliness, large grains

Table 2. Resistance to leaf rust and stem rust in the condition of infection background.

Variety	P. recondita			P. graminis		
	Max. value, %, type	P+ maximum	P average	Max. value, %, type	P maximum	P average
	Average 1977-1978					
Yubiley	5R	1	0.7	100VS	100	90
Zg 4240/73	5R	1	0.7	0	0	0
Zg 4364/73	25M	15	15	0	0	0
Zg 887/73	25R	5	5	0	0	0
Zg 4293/73	5R	1	1	0	0	0
Sadovo 1	100VS	100	100	100VS	100	90
F 53-70	tR	0.4	0.4	100VS	100	90
Julia	80VS	80	72	100VS	100	87
F 54-70	tR	0.4	0.4	100VS	100	90
Blueboy	5R	1	0.7	100VS	100	100
Mironovskaya 808	100VS	100	100	100VS	100	100
Bezostaya 1	100VS	100	82	100VS	100	93
Lindon	5R	1	1	100VS	100	70
Krasnodarskaya 39	100VS	100	100	100VS	100	100
NE73640	80VS	80	44	tR	0.4	0.2
	Average 1978-1979					
NR 72/837	25M	15	8	100VS	100	100
Slavia	100VS	100	95	100VS	100	100
Partizanka	tR	0.4	0.2	100VS	100	100
Slavyanka	15M	8	6	100VS	100	100
Martonvasari 4	100VS	100	58	100VS	100	100
Absolvent	100VS	100	62	100VS	100	100
Bezostaya 1	100VS	100	75	100VS	100	100
Centurk	100VS	100	100	100VS	100	100
Ticonderoga	100VS	100	100	100VS	100	100
Samson	100VS	100	100	100VS	100	100
Nap Hal/Atlas 66	5R	1	0.7	25MR	10	5.5
Newton	80VS	80	49	65MR	26	23
Disponent	100VS	100	90	70M	28	27
Atlas 66	5MR	2	1.2	100VS	100	65
Budifen	25M	15	7.7	40M	24	12

+ $P = \frac{X.K}{Xst} \cdot 100$, X = % of attacks over the variety,

Xst = % of attacks over Mich. amber,

K = coefficient (R = 0.2, MR = 0.4, M = 0.6,

MS = 0.8, S = 0.9, VS = 1).

Table 3. Grain yield and physical properties of grain.

Variety	Origin	Grain yield, q/ha 1977	1978	1979	Average	Relative yield, %	1000-kernel weight	Hect. weight, kg	Number grains/ear
		--------- 1977-1978 ----------							
Yubiley	Bulgaria	68.4	97.2	-	82.8	135.0	41.8	78.3	36.06
Zg 4243/73	Yugoslavia	67.0	91.8	-	79.4	129.7	35.8	76.2	39.46
Zg 4364/73	Yugoslavia	69.6	88.8	-	79.2	129.4	36.6	77.4	41.38
Zg 847/73	Yugoslavia	65.6	90.6	-	78.1	127.6	37.7	75.1	43.42
Zg 4293/73	Yugoslavia	65.0	88.6	-	76.8	125.4	34.4	71.8	41.48
Sadovo 1	Bulgaria	59.2	79.6	-	69.4	113.3	47.2	76.7	--
F 53-70	Romania	57.2	80.6	-	68.9	112.5	41.9	79.3	33.6
Julia	Romania	61.4	74.8	-	68.1	111.9	43.7	81.0	31.85
F 54-70	Romania	58.6	76.4	-	66.6	108.8	40.9	80.3	31.58
Blueboy	USA	52.2	71.6	-	63.4	103.5	34.4	71.8	35.02
NE73640	USA	29.2	59.2	-	44.2	72.2	36.8	77.8	30.78
Mironovskaya 808	USSR	53.4	71.0	-	62.2	101.6	37.8	74.9	38.32
Bezostaya	USSR	52.2	70.2	-	61.2	100.0	41.6	77.7	34.34
Lindon	USA	51.0	68.6	-	59.8	97.7	34.7	77.8	34.48
Krasnodarskaya 39	USSR	44.4	62.8	-	53.6	87.5	40.9	72.9	37.50
		--------- 1978-1979 ----------							
NR 72/837	Austria	-	96.4	71.8	84.1	129.1	42.48	75.3	34.14
Slavia	Czechoslovakia	-	78.2	71.8	75.0	115.1	36.60	74.5	30.92
Partizanka	Yugoslavia	-	77.2	69.3	73.2	113.5	33.48	79.9	32.76
Slavyanka	Bulgaria	-	77.6	62.5	70.1	107.6	38.63	77.8	35.00
Martonvasari 4	Hungary	-	70.4	68.0	69.2	106.2	37.17	79.7	38.38
Absolvent	West Germany	-	73.6	57.5	65.6	100.6	40.02	80.0	37.68
Bezostaya 1	USSR	-	70.2	60.0	65.1	100.0	38.78	79.8	34.34
CI 13449/Centurk	USA	-	66.2	62.5	64.4	98.8	34.13	74.8	31.36
Ticonderoga	USA	-	85.2	40.0	62.6	96.1	31.50	70.5	35.82
Samson	Austria	-	61.6	65.0	63.3	97.2	32.90	78.0	36.00
Nap Hal/Atlas 66	USA	-	85.8	38.8	62.3	95.6	26.58	76.9	32.86
Newton/KS73112	USA	-	66.2	58.0	62.1	94.7	34.36	78.6	24.56
Disponent	West Germany	-	71.0	46.8	58.9	90.4	26.29	72.3	39.04
Atlas 66	USA	-	52.8	51.8	52.3	80.3	36.56	77.1	36.86
Budifen	Chile	-	56.6	43.0	49.8	74.4	26.93	70.4	37.98

(1000-grain weight is about 42.2 g) and high resistance to brown rust. The latter is a basic cause for low yields under the conditions of Dobroudja.

Yugoslavian varieties have comparatively smaller grains, 1000-grain weight being 34.4-37.7 g, but at the same time have a greater number of grains/ear (39.5-43.4 grains/ear) against 34.4 for Bezostaya 1 and 36.1 for Yubiley. An important character contributing to the high grain yields of these varieties is their complex resistance to diseases, their short stems (67-83 cm) and their resistance to lodging. They, however, possess insufficient winter-hardiness. The widely spread variety Sadovo 1 outyielded Bezostaya 1 by 8.2 q/ha (13.4%) but is at the same time inferior to the most productive varieties Yubiley and Zg 4240/73 by 14.3 q/ha and 10 q/ha, respectively. It forms very large grains (1000-grain weight = 47.9 g) and is highly resistant to lodging, but not to brown rust and powdery mildew.

The Russian variety Mironovskaya 808 is highly productive in many parts of the USSR but in our conditions performs similar to Bezostaya 1; that is, it is often attacked by brown rust, not very resistant to lodging, and it forms comparatively small grains. Grain yields of Krasnodarskaya 39 are rather low (87.6%), mainly due to susceptibility to powdery mildew and brown rust and lower resistance to lodging. Romanian varieties F 53-70, F 54-70 and Julia outyield Bezostaya 1 by 5.4-7.7 q/ha (8.8-12.6%) but are inferior in yield to Yubiley and the Yugoslavian varieties. F 53-70 and F 54-70 in the conditions of our country form high yields because of their high resistance to brown rust and good field resistance to powdery mildew. Considering their genetic potentials, it can be concluded that the productivity obtained is the highest attainable. Therefore, when speaking of intensive varieties, they are to be classified as much inferior to the Bulgarian and Yugoslavian ones. That is proved additionally by their stem height--112 and 110 cm, respectively, against 67-83 cm for the Yugoslavian varieties and Yubiley. Julia has a relatively shorter stem (102 cm) and is resistant to lodging but susceptible to brown rust That lowers its productive potential.

The three tested varieties originated from the USA are of low productive potential. That applies most to NE73640 that is much inferior to the standard in yielding (17 q/ha less) and occupies the last place. This is conditioned by several defects--susceptible to brown rust, low resistance to lodging, small grains (1000-grain weight = 36.8 g) and a small number of grains/ear (30.8 grains/ear). Lindon is inferior to the standard, also, irrespective of its resistance to brown rust and powdery mildew. It forms very small grains (1000-grain weight = 34.7 g) and is highly susceptible to lodging (up to 80%). Only Blueboy outyields Bezostaya 1 by 3.6% due to its good resistance to lodging and brown rust.

Of all varieties tested in the years 1977/78 and 1978/79 the Austrian variety NR 72/837 has yielded highest--84.1 q/ha (about

129.1%, against 100% for Bezostaya 1). It has short stems resistant to lodging, large grains and a comparatively large number of grains/ear. For the 2 years, its average 1000-grain weight was 42.5 g against 38.8 g for Bezostaya 1. The same character varies between 33.5-40.0 g for the next 5 higher yielding varieties. The advantages of NR 72/837, no matter whether commercially grown or used in hybridization, are determined by its very good resistance to powdery mildew and brown rust and by the very good quality of the grain.

The highly productive varieties Slavia and Partizanka yielded for the two years an average (1978-1979), respectively, of 75 q/ha and 73.2 q/ha, which is 115.1 and 113.5% compared to Bezostaya 1. In spite of this, these varieties are of no interest to Bulgarian wheat breeders because they have already developed a series of the same type but of higher productivity combined with a complex of other valuable characters.

The Bulgarian highly productive variety Slavyanka has very good quality of grain and yields 70.1 q/ha, its relative yield coming to 107.6%. For that reason, it takes up larger and larger parts of wheat growing areas of Bulgaria.

MV-4 yielded 69.2 q/ha (106.2%). Absolvent produced 65.6 q/ha (100.6%). Grain yields of the rest of the varieties vary between 64.4-49.8 q/ha, so they are of interest to us only as a breeding material.

The complex economical evaluation of the new varieties of bread wheats must include not only productivity, but its combination with good quality of grain and dough (as is the case of Bezostaya 1). The genotypic and phenotypic manifestation of quality indices refers mainly to physical properties of the grain, the content of protein and gluten, strength of the dough and the quality of the bread.

In both the years (1977-1978) all varieties tested manifested the same hereditary peculiarities with respect to protein content in the grain (Table 4). If compared to Bezostaya 1, high protein content occurred in the Romanian varieties F 54-70 and F 53-70, protein yields per unit area being respectively 2.26 and 1.92 q/ha higher. Protein content is high (14.0-14.5%) in NE73640, Julia and Zg 4293/73 too. With respect to protein content the Bulgarian variety Yubiley is on the level of the standard but, due to its high productivity, its protein yield/ha is highest--11.18 q/ha or with 2.84 q/ha more than the standard (134.1%). Sadovo 1 manifested a comparatively low protein %, but if measured as yield in q/ha it ranks close to Bezostaya 1. The Yugoslavian varieties Zg 4240/73 and Zg 4364/73 are of moderate protein content and take up the 3rd and 4th places. The Romanian varieties contain the greatest quantities of wet (36.4-40.2%) and dry (12.1-14.6%) gluten. Wet gluten in the Bulgarian varieties is 2% lower than Bezostaya 1 and in some Yugoslavian ones up to 3.3%. Blueboy has been estimated

Table 4. Quality of grain, flour and bread.

Variety	Grain protein %	Protein yield kg/ha	Vitreous kernel, %	Gluten of flour Wet %	Gluten of flour Dry %	Absorption %	Resistance of dough, min.	Weakening tence F.U.	Valorimeter consistence	Bread volume, %	Bread volume, ml	Bread Index (H:D)	Elasticity (5-excellent)
	Average 1977-1978												
Yubiley	13.69	111.8	50	30.1	10.9	55.5	6.32	52	65	510	0.50		4.2
Zg 4240/73	13.54	106.8	45	33.0	11.0	55.4	3.50	92	50	546	0.44		4.0
Zg 4364/73	13.50	105.2	47	30.0	10.9	54.3	3.25	60	52	505	0.39		3.0
Zg 887/73	12.78	99.2	44	28.8	9.8	56.9	4.25	80	52	498	0.40		3.5
Zg 4293/73	14.04	107.4	52	29.5	10.4	54.4	3.00	95	47	510	0.40		3.7
Sadovo 1	11.88	82.3	52	30.1	10.6	59.6	4.10	55	55	536	0.43		4.4
F 53-70	15.55	106.0	73	40.2	14.6	60.2	8.30	32	74	555	0.49		4.4
Julia	14.29	97.3	69	36.4	12.1	61.4	7.30	38	71	584	0.50		4.8
F 54-70	15.53	102.6	68	36.4	13.3	59.9	6.30	50	64	547	0.48		4.6
Blueboy	12.59	80.0	44	27.4	9.8	53.8	2.20	120	38	515	0.36		2.9
Mironovskaya 808	12.43	77.3	67	30.5	10.8	56.6	5.00	72	56	530	0.50		4.6
Bezostaya 1	13.72	83.4	64	32.1	11.1	59.7	7.00	35	69	537	0.49		4.6
Lindon	13.63	80.9	68	32.1	11.6	57.3	9.05	25	77	541	0.46		4.5
Krasnodarskaya 39	13.86	73.8	57	30.0	11.0	57.2	6.00	42	64	498	0.43		3.9
NE73640	14.52	65.0	62	36.6	13.2	59.6	7.15	45	69	553	0.48		4.5
	Average 1978-1979												
NR 72/837	14.88	125.1	52	29.9	10.7	58.6	4.10	65	55	531	0.42		3.9
Slavia	13.64	102.3	49	31.6	10.0	52.9	2.48	95	45	523	0.44		4.1
Partizanka	13.98	102.3	56	30.8	10.5	58.0	7.08	45	68	564	0.45		4.1
Slavyanka	14.28	100.1	58	31.6	11.6	57.9	8.48	35	74	564	0.42		4.6
Martonvasari 4	13.90	96.2	61	31.9	11.0	59.2	6.18	50	64	544	0.45		4.2
Absolvent	13.62	89.3	54	31.1	10.8	58.1	4.40	55	60	551	0.42		4.1
Bezostaya 1	13.09	85.2	56	30.6	10.4	58.5	7.00	45	68	563	0.46		4.6
Centurk	13.55	87.3	40	28.0	9.6	55.4	2.23	70	48	496	0.40		3.9
Ticonderoga	12.63	79.1	30	27.0	9.0	54.0	1.45	120	36	484	0.40		3.1
Samson	13.44	85.1	52	31.1	11.2	58.6	6.30	45	64	565	0.45		4.6
Nap Hal/Atlas 66	18.86	117.5	52	42.0	14.4	61.0	1.43	140	34	475	0.30		2.4
Newton	14.69	91.2	56	31.0	10.6	56.9	5.20	50	60	565	0.43		3.7
Disponent	15.09	88.9	57	30.1	10.8	58.8	6.32	70	63	555	0.43		3.7
Atlas 66	16.86	88.2	59	42.2	14.2	60.4	4.05	85	52	504	0.38		3.3
Budifen	12.63	62.8	44	28.6	9.4	51.4	1.50	95	40	509	0.40		3.0

as poor in gluten quantity and quality. Yubiley and the Yugoslavian varieties are inferior to Bezostaya 1 with respect to milling properties--2.4-5% lower dough yield, while Sadovo 1 and the Romanian varieties are on the level of the standard. Water-absorbing capacity of the dough of the Romanian varieties, Sadovo 1 and NE73640 is higher or equal to that of Bezostaya 1. All varieties studied are highly variable in dough resistance--from 2.2 (Blueboy) to 9.05 min. (Lindon). Keeping in mind the high degree of inheritance of this character and the valorimetric value, only can fully appreciate the high technological quality of the new bread wheat varieties. The most productive variety Yubiley has a very strong gluten and very good rheological properties of the dough (65 valorimetric value), thus, ranking close to Bezostaya 1 (4.5). This determines good quality of bread as well a very high H:D (0.50) and fine and elastic crumb. Yubiley is insignificantly inferior to Bezostaya 1 with respect to bread volume because of the moderate gassing capacity of the dough (4).

F 53-70 and Julia, outyielding Bezostaya 1, are also classified as strong wheats and manifest a very good bread quality. A maximum bread volume (634 ml) and an excellent quality of the crumb was recorded for Julia in 1977. F 54-70 has high technological properties too but it yields 16.2 q/ha less than Yubiley. Besides its high productivity Sadovo 1 produces bread of good quality and medium strength with good rheological properties of the flour, not dependent on the different conditions of growing (4).

Typical of the highest yielding variety NR 72/837, one of the second group, is its comparatively high protein content and the good rheological properties of the dough and the bread. Protein yield/ha is 12.5 q/ha or 4.01 q/ha more (146.3%). The 2-year average protein % of Slavyanka and Partizanka is high too--14.28% and 13.88%, respectively, so the relative protein yield is accordingly higher--11.75 q/ha or 120%. Slavia, Martonvasari and Absolvent exceed Bezostaya 1 with respect to protein by 0.53-0.81%. Particularly valuable protein genotypes among the less productive varieties are Nap Hal/Atlas 66 (18.86%) and Atlas 66 (16.86), the wet gluten being up to 42%. Quality of their gluten and bread remains, however, unsatisfactory.

Content of wet and dry gluten in the flour of Slavyanka and MV-4 is a bit higher than that of Bezostaya 1. The rest of the varieties are almost on the level of the standard and possess a medium strength of the flour. Under the same conditions Ticonderoga and Budifen formed grain of lower protein content (12.63%) and gluten. Baking absorption of the flour of the first six varieties, except Slavyanka, is high (57.9-59.2%). The high technological qualities of the prospective varieties Slavyanka, Partizanka and MV-4, ranking in the class of Bezostaya 1, should be emphasized. Absolvent, NR 72/837 and Slavia are of medium strength and of good bread quality. The less productive varieties Samson, Newton and Disponent manifest a good quality of the dough and bread.

Finally, it is necessary to point out that with respect to their complex of valuable biological and economical characters, the best varieties for the years 1977 and 1978 are Yubiley and Sadovo 1, followed by the Yugoslavian and the Romanian varieties. The intensive variety Yubiley is of high productivity, possesses short stems resistant to lodging, high resistance to brown rust, ecological plasticity, very good rheological properties of the dough, and flour strength close to that of Bezostaya 1. Sadovo 1, besides its high productive potential, has good winterhardiness, resistance to lodging, good quality of the dough and bread, but it is not resistant to the three most common diseases.

Yugoslavian varieties Zg 4240/73, Zg 887/73, Zg 4364/73 and Zg 4293/73 are highly productive with short stems resistant to lodging, a complex resistance to diseases, medium to good quality of the bread, but of insufficient winterhardiness.

Romanian varieties F 53-70, F 54-70 and Julia have good productive potential and very good winterhardiness. The first two are highly resistant to brown rust. F 53-70 is identified as a strong wheat. The other two have very good quality of bread. Of all varieties tested in 1978-1979, NR 72/837 has performed best. It possesses high productivity (relative yield = 129.1%) due to its large grains, the large number of grains/ear, short stem, resistance to brown rust and powdery mildew, and good winterhardiness. These valuable characters combined with high protein content, good rheological properties of the dough and the bread manifest its potential usefulness.

The high-yielding varieties Slavia and Partizanka are of medium to good winterhardiness with short stems resistant to lodging, good resistance to powdery mildew (of Slavia) and to brown rust (Partizanka). Partizanka is a strong wheat of very good bread quality. Slavyanka also has good bread quality.

The Bulgarian variety Slavyanka is of higher productive potential than Bezostaya 1 and possesses medium to good winterhardiness. Besides, it is resistant to lodging and to brown rust. The high estimated technological qualities of its grain and flour, typical of the strong wheats only, determine its priority in industrial wheat growing.

References

1. Borojevic, S. 1975. Second International Winter Wheat Conference. Zagreb, Yugoslavia.

2. Govedarov, I., I. Todorov, V. Gotzova, Tzv. Rachinska. 1978. Rastenievadni nauki. XV, No. 6:32-42.

3. Govedarov, I., I. Todorov, V. Gotzova, Tzv. Rachinska. 1978. Rastenievadni nauki. XVI, No. 4:35-44.

4. Gozova, V. 1979. Mezhdunarodno selskostopansko spisanie. No. 2.

5. Petric, D., M. Saric, and R. Sekulic. 1977. Tehnoloske karakteristike novih Yugoslovenskih sorti psenice na podrucja. Novi Sad.

6. Stroike, J. E. and V. A. Johnson. 1975. Second International Winter Wheat Conference. Zagreb, Yugoslavia, June.

7. Todorov, I. 1972. First International Winter Wheat Conference. Ankara, Turkey, June 5-9.

8. Todorov, I., V. Gotzova, Tsv. Rachinska. 1975. Second International Winter Wheat Conference. Zagreb, Yugoslavia, June.

WHEAT IN NEPAL

P. S. Rana and M. A. Khan
Nepal

Abstract

The history of wheat in Nepal, production-related problems, and highlights of current research are discussed.

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Wheat is third most important cereal crop of Nepal after rice and maize in that order, respectively. Wheat has wide adaptability in Nepal. It grows from the terai (alluvial Gangetic plains that extends into southern Nepal) to the high mountain areas at the base of the Himalayan range. This area ranges from 100 m in the south to 3000 m above sea level in the north of the kingdom. In this range the climate varies from tropical to substropical and temperate. Most of the wheat cultivation in Nepal is in the terai region (65%).

The wheat area has trebled in the last decade. At present this crop is being grown on 364,000 hectares, an area which is about 15.83% of the total cultivated area of 2,300,000 hectares. As seen in Table 1 the wheat area and production are steadily increasing. There have been some years when unfavourable weather during the harvesting season drastically reduced the yield. However, the national average on a unit basis has not gone up. The low yield on a unit area basis on the national level is due to limited resources in some areas and also due to marginal land coming under wheat production. Since only 11% of the total cultivated area has irrigation facilities, water is one of the main factors limiting yield.

Most of the wheat grown in Nepal is planted in November-December and harvested in March-April. However, in the higher elevations the length of the growing season is longer. At altitudes of 2000 to 3000 meters wheat is planted in September-October and harvested in May-June, thereby taking seven to ten months to mature. It is interesting to note that there are some areas above 3000 meters in which wheat is grown as a summer crop. In such areas wheat is planted in April-May and harvested in October-November. Table 2 shows the areas and production of wheat in the different geographic regions of Nepal.

In general, environmental conditions in the terai are more favourable for disease development than in the hills. Leaf rust is the most common disease found in the terai, while in the hilly regions yellow and black rusts are more prevalent. Loose smut occurs frequently but with low intensity. Powdery mildew and bunt are commonly in the hills and valleys. Helminthosporium leaf

National Wheat Development Program, Bhairhawa.

Table 1. Area, production and average yield of wheat in Nepal.

Year	Area '000 ha	Production '000 m. tons	Average yield rate kg/ha
1961/62	112	138	1230
1962/63	112	138	1228
1963/64	113	139	1226
1964/65	100	126	1260
1965/66	118	147	1249
1966/67	126	159	1267
1967/68	192	205	1066
1968/69	208	233	1119
1969/70	226	265	1173
1970/71	228	193	846
1971/72	239	223	933
1972/73	259	312	1204
1973/74	274	308	1125
1974/75	291	331	1138
1975/76	329	387	1178
1976/77	348	362	1039
1977/78	366	411	1123
1978/79	364	454	1250

Source: Department of Food and Agricultural Marketing Services.

Table 2. Area and production of wheat in different agroclimatic regions of Nepal.

Year	Mountain		Hills		Terai		Nepal	
	Area	Prod.	Area	Prod.	Area	Prod.	Area	Prod.
1967/68	26.2	33.3	71.3	89.4	94.7	82.2	192.2	204.9
1968/69	27.4	35.4	76.2	99.9	104.3	97.4	207.9	232.7
1969/70	28.5	37.6	80.3	107.7	116.8	119.4	225.6	264.7
1970/71	28.7	28.9	83.7	82.8	116.0	81.6	228.4	193.3
1971/72	27.8	29.6	84.3	94.1	127.1	99.5	239.2	223.2
1972/73	27.9	25.3	82.4	94.9	149.1	192.3	259.4	312.5
1973/74	26.7	24.6	91.7	97.5	155.6	186.3	274.0	308.4
1974/75	23.6	20.5	93.2	99.1	174.0	211.2	290.8	330.8
1975/76	15.7	18.0	89.9	107.5	223.0	261.5	328.6	387.0
1976/77	13.6	11.5	101.1	114.1	233.6	236.3	348.3	361.9
1977/78	13.3	11.6	110.9	134.2	242.0	265.5	366.2	411.3

Area in '000 hectares
Prod. in '000 m. ton

blight is very common and Karnal bunt has been observed in some areas in the western and far western region.

Insects have not been an alarming problem for wheat cultivation in Nepal. However, wire worm damage to young seedlings has been reported from some areas in the terai. Thrips and stem borers are common but the damage is seldom great. Weevil in stored grain is a decided major pest of wheat.

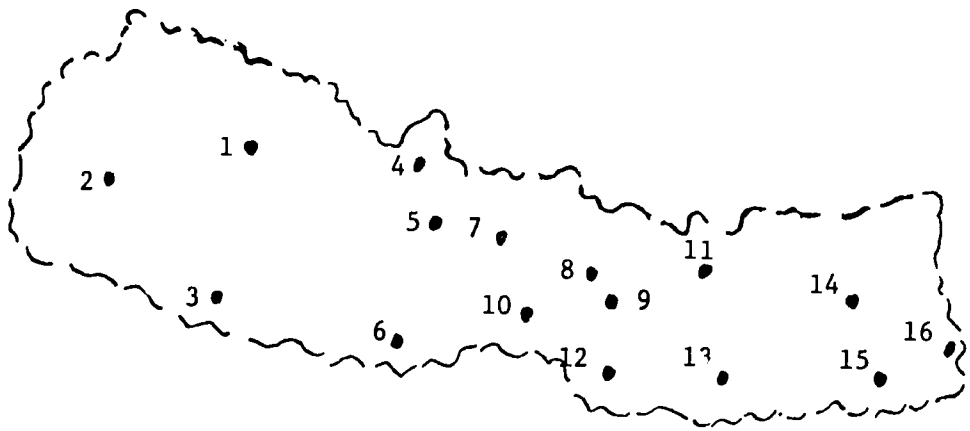
Origin of National Wheat Development Program.

Until two decades ago wheat was a secondary crop in Nepal mainly due to the lack of incentives among farmers who could not obtain the necessary agricultural inputs and extension service. Terai farmers used to grow rice in summer and leave the land fallow in winter. Only a few farmers were growing local varieties mostly without the application of chemical fertilizers and irrigation. To expedite wheat development in Nepal, His Majesty's Government of Nepal launched a "Grow More Wheat Campaign" in 1965-66 and encouraged farmers to put more land under wheat. This campaign was the first major step to popularize wheat cultivation in the country. The introduction of high yielding varieties from abroad and the establishment of the Agriculture Inputs Corporation (AIC) and Agriculture Development Bank (ADB) to make inputs and credits easily available through the agriculture extension personnel in the various districts, triggered a new wave of excitement among the farmers and consequently created a revolution among them to increase wheat acreages. This can be clearly seen from Table 1.

The National Wheat Development Program was established in 1972 to give a new impetus to wheat development in the country. This program, supported by various disciplines of crop science, conducts adaptive research at twelve experimental farms representing a wide agroclimate. Six of them are in the terai and six of them are in the hilly region. Figure 1 shows the location of these agriculture stations and farms. At present the National Wheat Development Program seeks to improve wheat research and extension aspects in the following ways: varietal program, cultural program, irrigation and mineral nutrition programs, plant pathological and entomological programs, farmer's field trials, minikits and seed multiplication at the farmer's field.

Varietal Program:--Western hills of Nepal were the traditional wheat-growing areas before the introduction of Mexican wheat strains that have had a far-reaching effect on wheat production. Lerma 52 from Columbia was released sixteen years ago for the mid-hills and some New Pusa series were recommended for the terai farmers. Lerma 52 became extremely popular in the Kathmandu valley and its surrounding areas due to its yield advantage over the local varieties. The farmers could also use its straw for domestic purposes.

The introduction of Mexican wheat strains was a spectacular success. These varieties had wide adaptability and broad spectrum of disease resistance. In the sixties, Lerma Rojo 64 became



1. Jumla
2. Doti
3. Nepalgunj
4. Marpha
5. Lumle
6. Bhairahwa
7. Khairanitar
8. Kakani
9. Khumaltar
10. Rampur
11. Kavre
12. Parwanipur
13. Janakpur
14. Pakhribas
15. Tarhara
16. Kankai

Figure 1. Map of Nepal and His Majesty's Government's Agriculture stations and farms where the National Wheat Development Program conducts research.

popular in the hills and Kalyansona in the terai. Lerma Rojo 64 is still grown by the hill farmers whereas Kalyansona with all its superior agronomic characters faded out of popular use by the farmers of Nepal because of its extreme susceptibility to leaf rust. RR 21 (Sonalika) was recommended in the early seventies to replace Kalyansona in the terai. Its popularity quickly spread to both terai, mid-hills and valleys. This variety was early-maturing and possessed bold, amber grain. It fitted well into our cropping pattern in the sense that it yielded better than any other strain even from late December planting (late harvesting of paddy is a common practice and delays normal wheat sowing and RR 21 was quite promising in such a situation).

Our cooperation with CIMMYT, Mexico; All India Coordinated Wheat Improvement Program; ICARDA, Syria; and Nebraska University, Nebraska, USA has enriched our program. The cultivation of a single genotype in a wide area was a risk as new races of diseases, especially leaf rust, could thwart the whole effort of the united development program. Attention was given to the diversification of varieties with different genetic background. NL 30, HD 1982 and UP 262 were recommended for general cultivat in the terai. NL 30 has sterility problem in eastern terai. It is reported to be doing well in some pockets of the western and far western terai region. HD 1982 did not perform very satisfactorily in terai even though it is cultivated in a limited scale. UP 262 released in 1978 is gaining popularity among the terai farmers. It has attractive grains and is resistant to leaf rust. However, its susceptibility to Karna 1 bunt is its major weakness and we are trying to distribute Karnal bunt-free seeds to the farmers.

The land races of wheat are being evaluated for their dormancy and profuse tillering. A crossing program with improved varieties has been initiated this year.

Our program gets F_2s, International Bread Wheat Screening Nursery (IBWSN); International Spring Wheat Yield Nursery (ISWYN); Elite Selection Yield Trial (ESYT) and crossing block from CIMMYT, Mexico. Priority has been given to the selection from F_2s. Most of the IBWSN materials were observed to be late in our environment.

The All-India Coordinated Wheat Improvement Program supplies us with the Uniform Regional Trials in addition to genetic stocks and disease nurseries.

The Regional Disease and Insect Screening Nursery (RDISN), Regional Wheat Yield Trial (RWYT) and Preliminary Observation Nursery (PON) from ICARDA have helped greatly in pathological and varietal aspects of wheat. The RDISN provides an opportunity to select disease-resistant types from hot spots of the country. RWYT and PON have helped to widen our genetic base.

The International Winter Wheat Performance Nursery (IWWPN) from Nebraska is being conducted every year to identify superior wheat strains for the higher elevation of Nepal. We have not been able to find a proper testing site for this nursery. Kathmandu is currently used as a testing site. Samson, Newton and Budifen are some of the wheat strains currently under multi-location testing.

Some of the most promising varieties that might be released next year are Tzpp-pl x 7c, HP 1209 and HD 2189 for terai and Jupateco-73 for the hills. Some of the selections made from the CIMMYT materials in Nepal are NL 247, NL 249, NL 255 and NL 256. They will undergo more yield testing and disease screening to be promoted as varieties in the future.

Varietal research in triticale obtained from CIMMYT, Mexico has been continued for almost a decade in the hills. It has been observed that triticales have no yield stability compared to wheat. They have advantages in diseases over wheat. They are also reported doing well on acidic soils in the hilly areas. However, their grain shrivelling does seem to be a major drawback. Research will be continued on a limited scale to keep abreast of varietal developments at CIMMYT and elsewhere.

Cultural and Mineral Nutrition Studies.--Sowing dates, time of application of irrigation, fertilizer rates and mode of application, and methods of sowing are varied and experiments are conducted with different varieties to find the best combination of practices that will give the highest yields. Such experiments are replicated at other HMG's farms and stations so that location difference can be found and recommendations made accordingly.

Plant Protection Studies.--Nationally and internationally developed varieties are tested in various international and regional disease trap nurseries at the HMG's farms and stations. Various parts of the country are surveyed for the presence of various plant diseases. This program also cooperates with the Plant Quarantine unit of the Plant Pathology Division to check the spread of infectious diseases of wheat.

Some New Findings:--UP 262 was released last year. It is a single gene dwarf variety similar to RR 21 in height. It has bold, white, hard lustrous grain and possesses very good chapati-making quality. It has field tolerance to rust and powdery mildew.

The results of the seeding date with variety experiment have been very interesting from the point of view of seeding date and variety interaction for yield. The date of seeding in which all the varieties had the highest yield was 16th November followed by 1st December. Regarding varieties, Jupateco-73 has consistently given the highest mean yield on almost all the seeding dates. So based on these 3 years data, the following conclusions can be drawn:

(i) The seeding date that can be recommended is the middle of November for all 4 varieties (RR 21, HD 1982, Jupateco-73 and Kalyansona) with the exception of Jupateco-73 which has more or less

equal consistency from the end of October to the middle of December.

(ii) In general among the varieties Jupateco-73 has consistently out-yielded all the others at each seeding. The results of this experiment clearly indicate the potentiality of Jupateco-73 which out-yields RR 21. It has not been released to the farmers because of red grains and its susceptibility to the leaf rust under late sown conditions.

The effect of Dithane M-45 in reducing the infection of Helminthosprium tritici causing leaf blight of wheat is of interest. The maximum disease score recorded in spraying treatments was 6 while that of the control was 7.99. The difference in scoring is not great, yet the relative percent increment in yield is more than 56% (2950 kg) over the control (1896 kg). Similarly there was a significant increment in 1000-grain weight. This was 16% (43.3 gms) more than the control (37.1 gms). Considering farmers economy and chemical effect on grain yield, it is suggested that one spraying of Dithane M-45 @ 2 kg/ha at 60 days after seeding in 800 liters of water is beneficial.

Treatments having no tillage with weeds dropped in line and covered with moist compost over moist soil was statistically superior in both locations in comparison to all other treatments as well as to the normal method of sowing. The highest mean grain yields of 1760 kg/ha and 3017 kg/ha were obtained with this treatment in Bhairahwa and Janakpur, respectively.

A wheat planting method of first ploughing, then broadcasting fertilizer and mixing it with soil, planking, broadcasting the wheat seeds and making ridges, and then irrigating the furrows just to make the ridges wet provided a very good plant stand, early germination and growth, better weed control, and improved wheat yields at Bhairahwa. This might be a better system of growing wheat in heavy soil with irrigation facilities. Dr. Torrey Lyons, CIMMYT Wheat Agronomist in Nepal, initiated this idea and developed an experimental ridger for this purpose. Irrigation and fertilizer recommendations have been formulated for rainfed and irrigated conditions.

Special Needs of NWDP.--The National Wheat Development Program is headquartered in Bhairahwa (in the terai region). Wheat also grows in the hills and mountains where the population pressure is intense and there is a great need for wheat yields to be increased on a per unit basis. Hence, NWDP to have a successful program for the hills, has to have a sub-station in the hilly area, especially where two crops of wheat can be grown. Man-power and facilities need to be developed to solve this problem.

PARTICIPANTS

Name	Country	Address
Bouattoura, N.	Algeria	Department Amelioration I.D.G.C. B.P. nº 16 El Harrach
Hachemi, L.	Algeria	I.D.G.C. B.P. nº 16 El Harrach
Laabasi, M.	Algeria	Direction Regionale de l' I.G.C. de Constantine Station Experimentale du Khroub Constantine
Chamorro, E.	Argentina	Facultad de Agronomia Universidad de Buenos Aires
Del Campo, H.	Argentina	Facultad de Agronomia Universidad de Buenos Aires Av. San Martin 4453 Buenos Aires
Tau, J.L.	Argentina	Departamento de Suelos Facultad de Agronomia Provincia de Buenos Aires
Haensel, H.	Austria	A-1080 Wien Langegasse 61/7
Ruckenbauer, P.	Austria	Institute for Crop Science and Plant Breeding University of Agriculture 33 Gregor Mendelstrasse A-1180 Vienna
Bolton, J.	Bangladesh	Bangladesh Agricultural Research Council 130-c Dhanmondi R.A. Road 1 Dacca 5
Hossain, A.B.S.	Bangladesh	Wheat Section Bangladesh Agricultural Research Institute Joydebpur, Dacca
Razzaque, A.M.D.	Bangladesh	Wheat Section Bangladesh Agricultural Research Institute Joydebpur, Dacca

Name	Country	Address
Vandam, J.	Belgium	Station d'Amelioration des Plantes 4 Rue de Bordia B-5800 Gembloux
Bochev, B.	Bulgaria	Centre of Biology Ul. R. Dimchev 2 Sofia
Gotzov, K.D.	Bulgaria	Institute for Wheat Tolbuhin
Rachinski, T.N.	Bulgaria	Institute for Wheat str. Georgi Dimitrov n.3 Tolbuhin
Hunt, L.A.	Canada	Department of Crop Science University of Guelph Guelph, Ontario
Knott, D.R.	Canada	Crop Science Department University of Saskatchewan Saskatoon, Sask.
Acevedo, J.	Chile	Estacion Experimental Carillanca Instituto de Investigaciones Agropecuarias Casilla 58-D Temuco
Ramirez Araya, I.	Chile	Instituto de Investigaciones Agropecuarias Casilla 5427 Santiago
Aboelenein Abdo, R.A.	Egypt	Field Crops Research Institute Agricultural Research Centre P.O. Box of A.R.C. Giza
Elhindi, M.H.	Egypt	Agronomy Department Faculty of Agriculture Mansoura University
Gomaa, A.S.	Egypt	Wheat and Barley Section Field Crops Research Institute Agricultural Research Centre Giza, Cairo
Khorshid, A.M.	Egypt	EL-ALFI st. nº 21 Azbakia Cairo

Name	Country	Address
Saari, E.E.	Egypt	CIMMYT P.O. Box 2344 Cairo
Baxter, D.G.	England	Rohm and Haas Company European Operations Chesterfield House Barter Street London WC1A 2TP
Cubitt, I.R.	England	Nickerson RPB Ltd. Joseph Nickerson Research Centre Rothwell, Lincs
Gohil, S.	England	Nickerson RPB Ltd. Joseph Nickerson Research Centre Rothwell, Lincs
Hughes, G.W.	England	Plant Breeding Institute Maris Lane Trumpington, Cambridge
Bonnemaizon, X.	France	Cacba P.B. 117 64003 Pau Cedex
Dorlencourt, G.	France	Gavadour Cargill Centre de Recherches 28310 Janville
Hardouin, J.-P.	France	Ets. C.C. Benoist Ferme de Moyencourt 78910 Orgerus
Koller, J.	France	INRA Station d'Amelioration des Plantes BV 1540 F 21034 Dijon Cedex
Josset, J.P.	France	Gavadour Cargill Station de Recherche Semonville Cidex 1824 28310 Janville
Laudoyer, O.	France	CACBA P.B. 117 64003 Pau Cedex
Leturque, J.C.	France	France Canada Semences S.A. Champigny en Beauce 41330 La Chapelle Vendomoise

Name	Country	Address
Martin, P.	France	UCOPAC Boite Postale 3 77390 Verneuil-L'Etang
Rousset, M.	France	Lot. Le Petit Pre Mirefleurs/637030 Les Martres de Veyre
Sunderwirth, S.	France	Unisigma 60480 Froissy
Sutra, G.	France	Rohm and Haas Company 28 Rue Jean Favier 31500 Toulouse
Thiebault, G.	France	Claeys-Luck S.A. 9, ure de Touraine 59112 Annoeullin
Quandalle, Ch.	France	Claeys-Luck, S.A. 9 rue de Touraine 59112 Annoeullin
Lange, J.	German Federal Rep.	Osterstr. 71 2000 Hamburg 19
Balla, L.	Hungary	Agricultural Research Institute Hungarian Academy of Sciences Martonvasar
Barabas, Z.	Hungary	Cereal Research Institute Szeged
Chopra, V.L.	India	Division of Genetics Indian Agricultural Research Institute New Delhi 110012
Rao, M.V.	India	Wheat Project Directorate I.A.R.I. New Delhi-110012
Abood, N.M.	Iraq	Central Laboratory Grain Board of Iraq P.O. Box 329 Baghdad
Gallagher, E.J.	Ireland	Department of Agriculture University College Lyons State Newcastle PO C.O. Dublin

Name	Country	Address
Atsmon, D.	Israel	The Weizmann Institute of Science Rehovot
Blum, A.	Israel	The Volcany Center, ARO P.O. Box 6 Bet Dagan
Eyal, Z.	Israel	Department of Botany Tel-Aviv University Ramat-Aviv Tel-Aviv
Alessandroni, A.	Italy	Istituto Sperimentale per la Cerealicoltura Via Cassia, 176 Roma
Lafiandra, D.	Italy	Germplasm Institute Via Amendola 165/A 70100 Bari
Pezzali, M.	Italy	Istituto Sperimentale per la Cerealicoltura Via Cassia 176 Roma
Duwayri, M.A.	Jordan	Faculty of Agriculture University of Jordan Amman
Ghosheh, Z.S.	Jordan	Agricultural Research Division Agricultural Research and Ex- tension Department P.O. Box 226 Amman
Abi Antoun, M.D.	Lebanon	American University of Beirut Faculty of Agriculture Beirut
Alameddine, M.A.	Lebanon	Division of Field Crops Agricultural Research Institute Tel-Amara, Rayak
Anderson, R.G.	Mexico	CIMMYT Londres 40 Mexico 6, D.F.
Byerlee, D.R.	Mexico	CIMMYT Apartado Postal 6-641 Mexico D.F.

Name	Country	Address
Klatt, A.	Mexico	CIMMYT Apartado Postal 6-641 Londres-40
Mondragon, C.	Mexico	Agrindustrias S.A. Genova 33- P.H. Mexico 6, D.F.
Nelson, W.L.	Mexico	CIMMYT Londres 40 Mexico 6, D.F.
Quinones, M.A.	Mexico	Edif. Ucay M. Aleman 666 Sur Ciudad Obregon, Sonora
Varughese, G.	Mexico	CIMMYT Londres 40 Apartado Postal 6-641 Mexico 6, D.F.
Vazquez, G.	Mexico	CIMMYT Londres 40 Mexico 6, D.F.
Vela, M.	Mexico	Agrindustrias S.A. Genova 33, P.H. Mexico 6, D.F.
Amri, A.	Morocco	Institut Agronomique et Veterinaire Hassan II Agdal Rabat
Burleigh, J.R.	Morocco	US Embassy B.P. 120 Rabat
Ezzahiri, B.	Morocco	Laboratoire de Phytopatologie B.P. 704 Institut Agronomique et Veterinaire Hassan II Rabat-Agdal
Gallagher, L.W.	Morocco	B.P. 120 Rabat
Jouve, Ph.	Morocco	Institut Agronomique et Veterinaire Hassan II B.P. 704 Rabat

Name	Country	Address
Quassou, A.	Morocco	INRA B.P. 415 Av. Nasr Rabat
Khan, A.M.	Nepal	Integrated Cereal Project P.O. Box 1336 Kathmandu
Rana, P.S.	Nepal	National Wheat Development Program Bhairhawa Agricultural Farm Bhairhawa Rupendehi
De Jong, H.C.	Netherlands	Cebeco-Handelsraad Plantage Willem III 3921 DZ Elst (U)
Kramer, Th.	Netherlands	Institute of Plant Breeding Agricultural University P.O. Box 386 6700 AJ Wageningen
Rai, R.K.	Netherlands	Cebeco-Handelsraad Plant Breeding Station P.O. Box 139 8219 PR Lelystad
Roothaan, M.E.	Netherlands	D.J. van der Have B.V. P. O. Box 1 4410 AA Rilland
Spiertz, H.J.	Netherlands	Centre for Agrobiological Research P.O. Box 14 6700AA Wageningen
Wouda, K.P.	Netherlands	Elensterweg 20 Ulrum
Gaunt, R.E.	New Zealand	Microbiology Department Lincoln, University College of Agriculture Canterbury
Sanderson, F.R.	New Zealand	Crop Research Division DSIR Private Bag Christchurch
Ringlund, K.	Norway	Department of Farm Crops Agricultural University Box 41 1432 AS-NLH

Name	Country	Address
Hepworth, H.M.	Pakistan	CIMMYT c/o Lapsa P.O. Box 1237 Islamabad
Noor-Ullah, M.	Pakistan	Parc P.O. N01031 Islamabad
Tahir, M.	Pakistan	Pakistan Agricultural Research Council P.O. Box 1031 Islamabad
Romero-Loli, M.J.	Peru	Universidad Nacional Agraria La Molina Apartado 456 Lima-1
Jakubiec, J.	Poland	Institute of Genetics & Plant Breeding Nowoursynowska str. 166 02-975 Warszawa
Sowa, W.	Poland	Plant Breeding and Aclim.Institute Radiation Biology Department Radzikow 05-870 Blonie
Witowski,	Poland	Plant Breeding Experimental Station Smolice
Wolski, T.	Poland	ZHRN-UNION of Plant Breeding and Seed Production Wspolna 30 Warszawa
Smit, H.A.	South Africa	Small Grain Center Private Bag X29 Bethlehem 9700
Stander, B.J.	South Africa	Welgevallen Private Bag X5023 Stellenbosch 7600
Alaman Castro, M.C.	Spain	INIA Banco de Germoplasma Apartado 127 Alcala de Henares
Alvarado Cordobes, M.	Spain	Servicio de Defensa contra Plagas Carretera de Utrera s/n Sevilla

Name	Country	Address
Arzadun, J.F.	Spain	Departamento de Cereales y Leguminosas INIA Apartado 127 Alcala de Henares
Atienza, E.	Spain	Agrar S.A. Monasterio de Cogullada Zaragoza
Beltran, E.	Spain	Eurosemillas S.A. Apartado 37 Cordoba
Bigeriego, M.	Spain	INIA Crida 6 Apartado 127 Alcala de Henares
Branas, M.	Spain	Departamento de Cereales y Leguminosas INIA Apartado 127 Alcala de Henares
Bueno, M.A.	Spain	Banco de Germoplasma INIA Apartado 127 Alcala de Henares
Carrillo, J.M.	Spain	Departamento Genetica Agraria Escuela T.S. Ing. Agronomos Ciudad Universitaria Madrid-3
Casanova, C.	Spain	Banco de Germoplasma INIA Apartado 127 Alcala de Henares
Chueca, M.C.	Spain	Departamento de Cereales y Leguminosas INIA Apartado 127 Alcala de Henares
Comenge, J.	Spain	Agrar S.A. Monasterio de Cogullada Zaragoza
Domenech, Z.	Spain	Servicio de Defensa contra Plagas Tomas de Aquino 1 Cordoba

Name	Country	Address
Flores, R.	Spain	Departamento de Genetica Escuela T.S. Ingenieros Agronomos Apartado 246 Cordoba
Garcia Olmedo, F.	Spain	Departamento de Bioquimica Escuela T.S. Ingenieros Agronomos Ciudad Universitaria Madrid-3
Gil Gomez, J.L.	Spain	S.E.A. Bravo Murillo 101 Madrid-20
Godia, E.	Spain	Monte Julia Lerida
Gomez-Arnau, J.	Spain	Mahissa Borjas Blancas Lerida
Gonzalez Moreno, A.	Spain	Departamento de Cereales y Leguminosas INIA Apartado 127 Alcala de Henares
Granda, M.L.	Spain	Departamento de Cereales y Leguminosas INIA Apartado 127 Alcala de Henares
Ibanez, L.	Spain	Centro de Capacitacion y Experiencias Agrarias Granja Vinalta Apartado 84 Palencia
Jalvo, C.	Spain	Departamento de Genetica Agraria Escuela T.S. Ingenieros Agronomos Ciudad Universitaria Madrid-3
Jimenez-Diaz, R.M.	Spain	Catedra de Patologia Vegetal Escuela T.S. Ingenieros Agronomos Apartado 246 Cordoba
Jousseaume, Ch.	Spain	Rohm and Haas Espana S.A. Provenze 216, 3º Barcelona-36

Name	Country	Address
Jouve de la Barreda, N.	Spain	Departamento de Genetica Facultad de Ciencias Universidad de Alcala de Henares
Juan-aracil, J. de	Spain	INIA Unidad de Cereales, Crida 10 Apartado 589 Jerez de la Frontera
Linuesa, R.	Spain	CUSESA Paseo de la Habana 56 Madrid-16
Lopez Guitian, J.	Spain	Huesca nº 27, 1 C Madrid-20
Marin-Sanchez, J.P.	Spain	Catedra de Patologia Vegetal Escuela T.S. Ing. Agronomos Apartado 246 Cordoba
Martin, L.	Spain	Departamento de Genetica Escuela T.S. Ing. Agronomos Apartado 246 Cordoba
Martin-Sanchez, J.A.	Spain	Mahissa Ciba-Geigy Subdivision Semillas Af. Estacion s/n Borjas Blancas Lerida
Martinez, G.	Spain	Cera del Arrecife 5 Cordoba
Martinez-Vazquez, M.	Spain	Departamento de Cereales y Leguminosas INIA Apartado 127 Alcala de Henares
Mateo Box, J.M.	Spain	Catedra de Fitotecnia Escuela T.S. Ing. Agronomos Ciudad Universitaria Madrid-3
Mears, L.G.	Spain	Embassy of USA Serrano 75 Madrid-6
Merelles, G.	Spain	Zurbano 67 Madrid

Name	Country	Address
Mesquida, F.	Spain	Departamento de Cereales y Leguminosas INIA Apartado 127 Alcala de Henares
Michelena, A.	Spain	Escuela T.S. Ingenieros Agronomos Carretera de Huesca, Km. 3 Lerida
Monteagudo, I.	Spain	Departamento de Genetica Agraria Escuela T.S. Ingenieros Agronomos Ciudad Universitaria Madrid-3
Montes, F.J.	Spain	INIA San Jose de la Rinconada Sevilla
Montoya, J.L.	Spain	INIA Apartado 733 Valladolid
Morillo, F.	Spain	Centro Regional S.E.A. Apartado 99 Montilla Cordoba
Pinochet, J.G.	Spain	Agrar S.A. Monasterio de Cogullada Zaragoza
Ramirez Gimeno, V.	Spain	INIA Crida 10 Apartado 240 Cordoba
Refoyo, A.	Spain	Semillas Pacifico S.A. Apartado 11 El Arahal Sevilla
Rodriquez Losada, C.	Spain	APROSE Desengano 10 Madrid-13
Rodriquez Martinez, F.	Spain	Mateo Lopez 7 Madrid
Royo, C.	Spain	Escuela T.S. Ingenieros Agronomos Carretera de Huesca, Km. 3 Lerida
Ruiz, J.L.	Spain	Departamento de Cereales y Leguminosas INIA Apartado 127 Alcala de Henares

Name	Country	Address
Salazar, J.	Spain	Departamento de Cereales y Leguminosas INIA Apartado 127 Alcala de Henares
Sanchez-Monge Laguna, E.	Spain	INIA Crida 10 Apartado 240 Cordoba
Sanchez-Monge Parellada, E.	Spain	Departamento de Genetica Agraria Escuela T.S. Ingenieros Agronomos Ciudad Universitaria Madrid-3
Santiago, M.	Spain	Departamento de Genetica Escuela T.S. Ingenieros Agronomos Apartado 246 Cordoba
Segura, A.	Spain	Agrar S.A. Monasterio de Cogullada Zaragoza
Silvela, L.	Spain	Semillas Agricolas Garcia Morato nº 4 Madrid
Sobrino, E.	Spain	Cecosa Genova 9 Madrid-4
Soler, M.C.	Spain	Departamento de Cereales y Leguminosas INIA Apartado 127 Alcala de Henares
Torres, J.V.	Spain	Departamento de Cereales y Leguminosas INIA Apartado 127 Alcala de Henares
Vadillo, J.	Spain	Semillas Agricolas Garcia Morato 4 Madrid-20
Valdivieso, D.	Spain	Departamento de Genetica Agraria Escuela T.S. Ingenieros Agronomos Ciudad Universitaria Madrid-3

Name	Country	Address
Valles, J.R.	Spain	Orense 18 Madrid
Vazquez, J.F.	Spain	Departamento de Genetica Agraria Escuela T.S. Ingenieros Agronomos Ciudad Universitaria Madrid-3
Villalba, A.	Spain	Huesca nº 27, 1º C Madrid
Wiklund, K.	Spain	Svalov AB El Puy Ibarra I, nº 9 Estella Navarra
Ahmed, M.S.	Sudan Democ. Rep.	New Halfa Research Station P.O. Box 17 New Halfa
El Ahmadi, A.B.	Sudan Democ. Rep.	Agricultural Research Corporation Gezira Research Station P.O. Box 126 Wad Medani
Denward, Th.	Sweden	Svalov AB S-288 00 Svalov
Kristiansson, B.	Sweden	Svalov AB S-268 00 Svalov
Svensson, G.	Sweden	Weibullsholm Plant Breeding Institute Box 520 S-261 24 Landskrona
Fossati, A.	Switzerland	Station Federale de Recherches Agronomiques de Changins CH-1260 Nyon
Paccaud, F-X.	Switzerland	Station Federale de Recherches Agronomiques de Changins CH-1260 Nyon
Archid, A.	Syria	Agricultural Research Center Douma Damascus
Srivastava, J.P.	Syria	ICARDA P.O. Box 5466 ALEPPO

Name	Country	Address
Petpisit, V.	Thailand	Kun Gut Rice Experiment Station Phatthalung
Halila, H.	Tunisia	Division Technique de l'Office des Cereales 30, rue Alain Savary Tunis
Altay, F.	Turkey	Agricultural Research Institute P.O. Box 17 Eskisehir
Atli, A.	Turkey	P.K. 226 Ankara
Durutan, N.	Turkey	P.K. 226 Ankara
Izgin, C.N.	Turkey	General Directorate of Agricultural Research P.O. Box 226 Ankara
Koycu, C.	Turkey	Ataturk University Ziraat Fakultesi Erzurum
Necati, C.	Turkey	Wheat Research and Training Center P.O. 226 Ankara
Prescott, M.J.	Turkey	CIMMYT P.K. 226 Ankara
Yakar, K.	Turkey	Wheat Research and Training Center P.K. 226 Ankara
Allan, R.E.	USA	209 Johnson Hall Washington State University Pullman, Washington 99164
Appleby, A.P.	USA	Crop Science Department Oregon State University Corvallis, Oregon 97331
Bolton, F.E.	USA	Crop Science Department Oregon State University Corvallis, Oregon 97331
Briggle, L.W.	USA	USDA-SEA-AR-NPS Room 331-A, Bldg. 005, BARC-W Beltsville, MD 20705

Name	Country	Address
Bright, D.L.	USA	740 Pendegast Circle Woodland, CA 95695
Byergo, K.	USA	AID US Department of State Washington D.C. 20523
Fenster, C.R.	USA	Panhandle Station University of Nebraska 4502 Ave I Scottsbluff, Nebr. 69361
Finney, K.F.	USA	US Grain Marketing Research Laboratory 1515 College Avenue Manhattan, Kansas 66502
Gallun, R.L.	USA	Department of Entomology Purdue University West Lafayette, In. 47907
Gardenhire, J.H.	USA	Texas A&M University Research and Extension Center 17360 Coit Road Dallas, Texas 75252
Jackson, R.I.	USA	DS/AGR/AP Room 413 RPC Agency for International Development Washington D.C. 20523
Johnson, V.A.	USA	324 Keim Hall, East Campus University of Nebraska Lincoln, NE 68583
Kenefick, D.G.	USA	Plant Science Department South Dakota State University Brookings, SD 57007
Kronstad, W.E.	USA	Crop Science Department Oregon State University Corvallis, Oregon 97331
Kuhr, S.L.	USA	330 Keim Hall, East Campus University of Nebraska Lincoln, NE 68583
Line, R.F.	USA	361 Johnson Hall Washington State University Pullman, WA 99164

Name	Country	Address
Mattern, P.J.	USA	154 Keim Hall, East Campus University of Nebraska Lincoln, NE 68583
McCuistion, W.L.	USA	Oregon State University Crop Science Department Ag. Hall 138 Corvallis, Oregon 97330
McNeal, F.H.	USA	Plant and Soil Science Department Montana State University Bozeman, MT 59717
McVey, D.V.	USA	Cereal Rust Laboratory University of Minnesota St. Paul, MN 55108
Moseman, J.G.	USA	Plant Genetics and Germplasm Institute Building 001, BARC-West Beltsville, Maryland 20705
Moss, D.N.	USA	Department of Crop Science Oregon State University Corvallis, Oregon 97331
Nelson, L.R.	USA	Texas A & M University Agricultural Research and Extension Center Drawer E Overton, Texas 75684
Olson, R.A.	USA	246 Keim Hall, East Campus University of Nebraska Lincoln, NE 68583
Peterson, C.J.	USA	USDA-SEA Rm. 109, Johnson Hall Washington State University Pullman, Wash. 99163
Pope, W.K.	USA	Plant and Soil Science Department University of Idaho Moscow, Idaho 83843
Qualset, C.O.	USA	518 Cleveland Ct. Davis, CA 95616
Quick, J.S.	USA	Agronomy Department NDSU Fargo, ND 58105
Sammons, D.J.	USA	Department of Agronomy University of Maryland College Park, Maryland 20742

Name	Country	Address
Schaller, C.W.	USA	7 Parkside Davis, CA 95616
Schmidt, J.W.	USA	322 Keim Hall, East Campus University of Nebraska Lincoln, NE 68583
Scott, N.H.	USA	Crop Science Department Oregon State University Corvallis, Oregon 97331
Smith, E.L.	USA	Agronomy Department Oklahoma State University Stillwater, OK 74074
Vogt, H.E.	USA	1145 Los Robles Davis, CA 95616
Watkins, J.E.	USA	448 Plant Science University of Nebraska Lincoln, NE 68583
Wilcoxson, R.D.	USA	Department of Plant Pathology University of Minnesota St. Paul, MN 55108
Wilson, J.A.	USA	DeKalb Hybrid Wheat, Inc. 1831 Woodrow Wichita, Kansas 67203
Borojevic, K.	Yugoslavia	Department of Biology Faculty of Natural Sciences Novi Sad
Borojevic, S.	Yugoslavia	Faculty of Agriculture Department of Genetics and Plant Breeding V. Vlahovica 2 21000 Novi Sad
Cvetko, M.	Yugoslavia	PPK Kutjevo 55 340 Kutjevo
Jost, M.	Yugoslavia	Faculty of Agricultural Science University of Zagreb Simunska c. 25 41000 Zagreb
Jost, M.	Yugoslavia	Pik "Vinkovci" Ro Poljoprivreda
Martincic, J.	Yugoslavia	Agricultural Institute Osijek

Name	Country	Address
Martinic, Z.	Yugoslavia	Faculty of Agriculture Institut of Plant Breeding and Production University of Zagreb 41000 Zagreb
Mihaljev, I.	Yugoslavia	Faculty of Agriculture 21000 Novi Sad Veljka Ulahovica 2
Milutin, B.	Yugoslavia	Agricultural Institute Osijek
Potocanac, J.	Yugoslavia	Institute for Breeding and Production of Field Crops 41000 Zagreb Rajtariceva 65
Rade, M.R.	Yugoslavia	Institute for Breeding and Production of Field Crops 41000 Zagreb
Slobodan, T.	Yugoslavia	Institute for Breeding and Production of Field Crops 41000 Zagreb
Stamenkovic, S.	Yugoslavia	Faculty of Agriculture Institute for Breeding and Production of Field Crops 21000 Novi Sad