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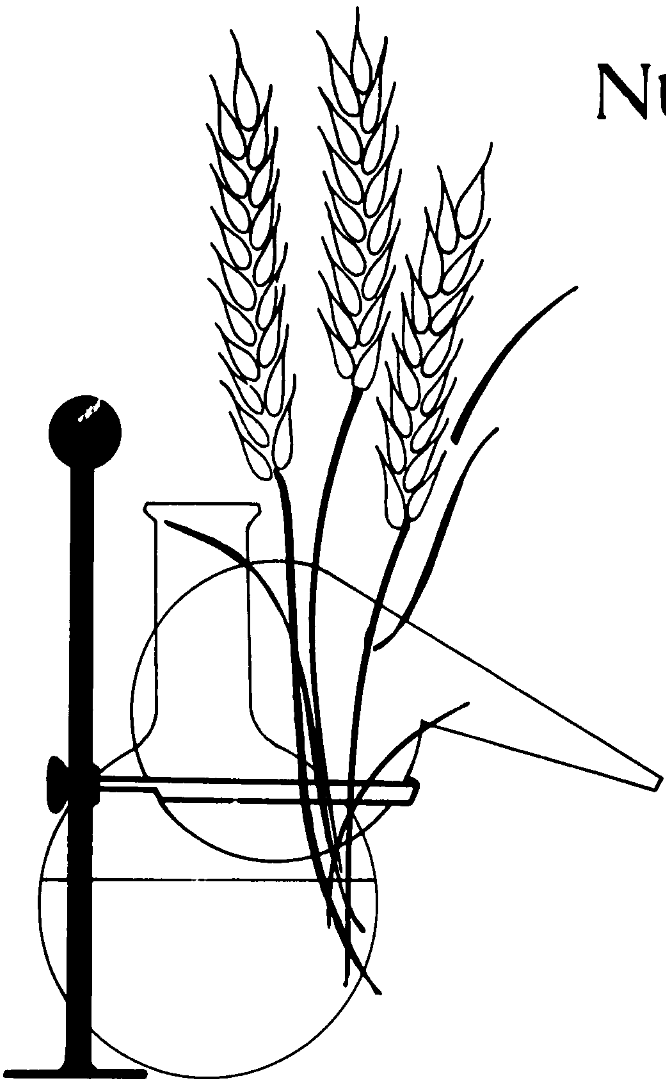
Genetic Improvement of Productivity and Nutritional Quality of Wheat



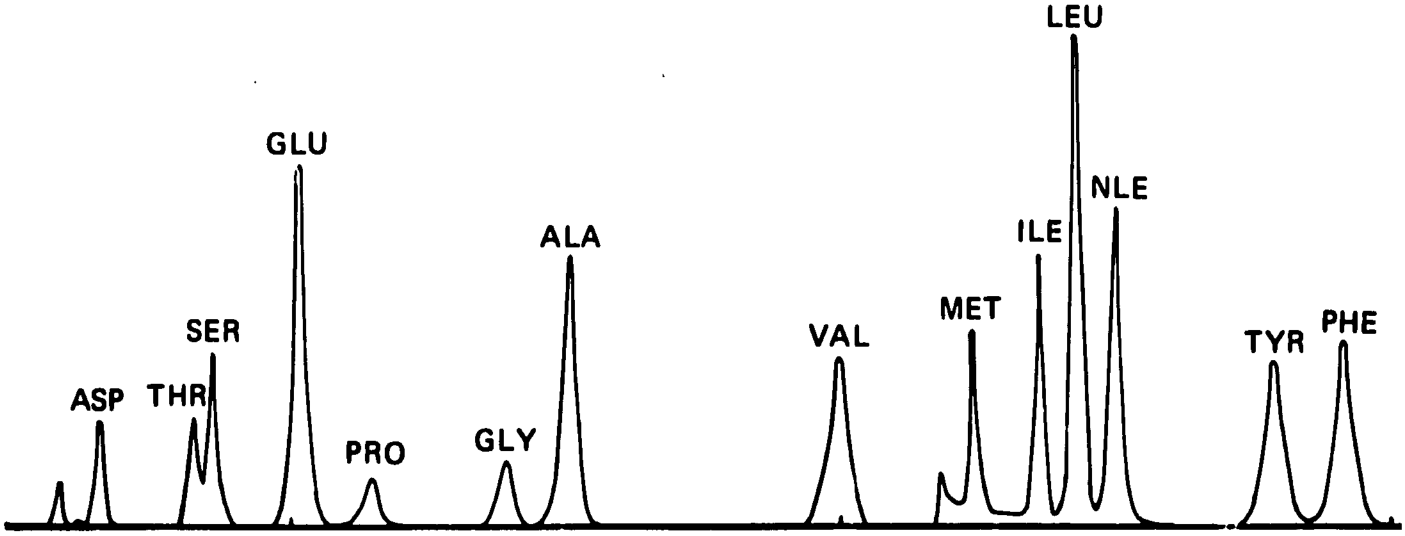
Final Report of Research Findings

CONTRACT NO. AID/csd-1208
JULY 1, 1966 - MARCH 31, 1974
CONTRACT NO. AID/ta-c-1093
APRIL 1, 1974 - DECEMBER 31, 1979

U.S. DEPARTMENT OF AGRICULTURE
SCIENCE AND EDUCATION ADMINISTRATION
AGRICULTURAL RESEARCH

U.S. INTERNATIONAL DEVELOPMENT
CORPORATION AGENCY
AGENCY FOR INTERNATIONAL DEVELOPMENT

UNIVERSITY OF NEBRASKA-LINCOLN
INSTITUTE OF AGRICULTURE
AND NATURAL RESOURCES
DEPARTMENT OF AGRONOMY



FINAL REPORT

OF

RESEARCH FINDINGS

GENETIC IMPROVEMENT OF PRODUCTIVITY
AND
NUTRITIONAL QUALITY OF WHEAT

July 1, 1966 - December 31, 1979

Principal Investigators

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Contract No. AID/csd-1208
(July 1, 1966 - March 31, 1974)

and

Contract No. AID/ta-C-1093
(April 1, 1974 - December 31, 1979)

Agency for International Development
Washington, D. C.

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NARRATIVE SUMMARY OF ACCOMPLISHMENTS AND UTILIZATION

Genetic variation for grain protein of at least 5 percentage points exists in hexaploid wheat based on analyses of more than 20,000 hexaploid, t raploid, and diploid accessions in the USDA World Collection and other research at Nebraska. Genetic variation for lysine, the first limiting amino acid in wheat protein, unlike maize, barley and sorghum, is limited, amounting to no more than 0.5 percentage point.

Lysine, expressed as percent of protein, is negatively correlated with protein at levels of protein up to 15%. A strong positive correlation exists between lysine per unit weight of grain and protein content of the grain. The amount of lysine and all other essential amino acids in wheat grain can be effectively increased by increasing protein content.

Major genes affecting grain protein content were identified in the Atlas 66 and Nap Hal varieties. Genes with modest effect on lysine were found in CI13449 and Nap Hal. The genes were combined via hybridization and were successfully transferred to productive short-statured winter and spring wheats which, since 1975, have been routinely distributed to breeders in developing countries.

Minor genes affecting protein are widespread in common and durum wheat. Selection for protein in more than 20 early generation hybrid populations of CIMMYT spring wheat, none of which was known to possess genetic variability for protein, successfully identified productive high protein lines with excellent potential for direct use or for breeding purposes in developing countries.

An international winter wheat evaluation network, currently involving 68 test sites in 38 countries, which was established in 1969, has been an effective vehicle for early identification of new high-yielding winter varieties with high performance stability and broad international adaptation.

The potential value of Bezostaya 1 as a commercial variety for production in Thrace and Western Anatolia in Turkey was initially identified by its performance in the International Winter Wheat Performance Nursery (IWWPN). Bolal, a stem rust-resistant variety selected in Nebraska and also tested in the IWWPN, now is a leading variety on the Anatolian Plateau of Turkey, and, together with Bezostaya 1, is significantly contributing to more stable and increased wheat production in Turkey.

Lancota, a productive, high protein rust-resistant hard winter wheat selected in Nebraska and tested in the IWWPN, was released jointly by Nebraska, Kansas, Texas, South Dakota, and the USDA in 1975. Its protein advantage over other productive hard winter varieties ranges from 0.5 to 2 percentage points.

Superior performance in the IWWPN of Sava and Partizanka from Yugoslavia, Kavkaz and Aurora from the USSR, Talent from France, Yubiley from Bulgaria, and Centurk from Nebraska has led to their extensive use by breeders as parent varieties in crosses. Lancota, Dacia, Favorit, Bacha, Moldova and Sentinel were identified as moderately productive varieties with higher-than-normal grain protein content based on their performance in the IWWPN.

Belinda, a productive stem rust-resistant wheat from the Nebraska breeding program, was named and released in the Republic of South Africa in 1971. It occupies a relatively small but important acreage in higher elevation production areas of South Africa.

An experimental line derived from an Atlas 66 cross and selected in the German Democratic Republic combines high productivity with high grain protein content under German production conditions. It is currently undergoing evaluation in official GDR state trials for possible registration.

NE 7060, selected in Nebraska from the complex cross Favorit/5/Cirpiz//Jang Kwang/4/Atlas 66/Comanche/3/Velvet, is currently being evaluated in the IWWPN. It possesses an attractive combination of winterhardiness, productivity, large seed, high grain protein content, acceptable milling and baking properties, disease resistance (rusts and mildew) and short straw. It is being extensively utilized as a parent variety by breeders in several countries.

Short-statured winter and spring experimental lines from the third cycle of protein breeding in Nebraska in which elevated protein and lysine have been combined with high productivity and other desirable agronomic traits, are distributed annually to breeders in developing and developed countries in a High Protein-High Lysine Observation Nursery. The nursery, which was initiated in 1975, currently is distributed each year to 55 cooperators.

Five hundred forty-four seed requests for high protein-high lysine germplasm from the Nebraska project were filled between 1966 and 1979. Requests for publications and reports during the same period totalled 1090 and came from every wheat-producing country including the People's Republic of China.

Research results from the project were published in 113 technical papers and in 22 reports.

Four international wheat conferences and an international workshop on seed protein were organized by project personnel. The conferences were held in Ankara, Turkey (1972), Porto Alegre, Brazil (1974), Zagreb, Yugoslavia (1975), and Madrid, Spain (1980); the seed protein workshop was held in Washington, D. C. in 1974. Proceedings were published and distributed from each of the conferences.

Thirteen graduate students associated with the project received Ph.D. degrees; six students received the M.S. degree. Seven of the graduate students were from developing countries. Ten agricultural scientists from 7 foreign countries received non-degree training on the project for periods of six months to one year.

Genetic studies indicate that Atlas 66 carries two or more major genes for protein, one of which is linked with a gene for adult plant leaf rust resistance. The Atlas 66 genes affect the level of protein in the starchy endosperm, the portion of the wheat kernel that is milled into white flour. Chromosome 5D of Atlas 66 carries a major gene for protein and chromosome 5A a gene with less effect.

Transgressive segregation for high and low protein in progenies of Atlas 66/Nap Hal provide evidence that at least one of the protein genes in Nap Hal is different from those in Atlas 66.

Genetic increases in lysine provided by C.I.13449 and Nap Hal, although limited, are of sufficient magnitude to be manipulated in breeding programs and to overcome the depression of lysine % of protein that is normally associated with elevation of protein.

Laboratory procedures and laboratory equipment modifications were developed to streamline the screening of large numbers of samples for protein and lysine. Moisture equilibrating cabinets with capacity to hold 10,000 samples eliminate the need for individual sample moisture determinations. An automatic amino acid analyzer was modified with 4 short ion-exchange columns to shorten lysine processing time to 8 minutes per sample.

Chemical analyses of protein and essential amino acids are reliable indicators of the nutritional value of wheat. Bioassays involving small animals and human subjects at Lincoln, Nebraska and convalescing malnourished children at the British-American hospital in Lima, Peru provided evidence that Atlas 66 and its high protein derivatives offer a significant advantage over ordinary wheats in terms of nutrition if consumed on a whole grain basis.

Physiological studies indicated that high grain protein in wheat involves elevated nitrate reductase activity, more complete translocation of nitrogen from plant foliage to the seed, and more nitrogen absorption by the wheat plant roots.

Significant associative nitrogen fixation could not be demonstrated for wheat grown in Nebraska.

A significant loss of nitrogen from wheat plants during grain maturation occurs in the form of ammonia. Loss by other forms of gaseous nitrogen could not be demonstrated.

SIGNIFICANCE

The opportunities for as well as constraints to nutritional improvement of wheat are better understood after 13 years of research in the Nebraska wheat protein project.

Genetic variation for protein is substantial; genes that influence protein appear to be widespread among the wheats of the world. Despite strong influence of environment on protein content, it is amenable to manipulation by breeding, provided key relationships of protein with other traits are understood.

Grain yield unquestionably influences protein content. High yields tend to reduce protein content of the grain but not as frequently nor as strongly as many breeders believe. Significant negative correlations between yield and protein occur in only 2/3 of the IWWPN trials and the amount of protein variation attributable to yield differences usually is very low, and seldom exceeds 25%. Selection for high protein independently of grain yield is likely to be ineffective. Protein differences among equally productive rows, on the other hand, are a reliable indication of true genetic differences.

Wheat literature contains reports that high protein in wheat is associated with small or shrivelled seed; that semi-dwarf varieties, because of shorter straw, are likely to be low in protein; and finally that lower energy requirements of carbohydrate synthesis compared with protein synthesis, of necessity will cause varieties with elevated protein to be less productive than lower protein varieties. Our data from international trials provide no evidence that there is a consistent negative relationship between seed size and protein although seed shrivelling can lead to non-genetic elevation of protein. Further, we are unable to demonstrate a significant relationship between plant height and seed protein; in fact, most of the high protein selections from our third breeding cycle are semi-dwarf types. Finally, productive high protein varieties of wheat have been developed and suggest that theoretical calculations of energy constraints to protein production in wheat may need to be reconsidered.

Thirty percent increase of the lysine content of wheat protein would contribute enormously to its higher utilization by monogastric animals. To do so would require large additional genetic variation for lysine that has not been found in wheat as it has in maize, barley and sorghum. The modest genetic variability for lysine uncovered to date in wheat is only of sufficient magnitude, if utilized, to counteract the depression of lysine typically associated with elevation of protein up to the 15% level.

It must be emphasized that genetic variability for protein does exist, and if utilized by breeders, can effectively make wheat more nutritious because of the associated increases in lysine and all of the other essential amino acids on a grain weight basis. In the absence of large genetic differences in lysine in wheat, the manipulation of protein is the only viable course of action available to breeders provided they can achieve the increases without adversely affecting grain yield.

A large amount of high protein wheat germplasm that possesses high yield potential, short straw, large seed, and disease resistance now exists in the Nebraska-USDA project at Lincoln. It represents significant improvement over the earlier non-productive, tall, high protein varieties like Atlas 66 and Nap Hal and their first breeding cycle derivatives. The germplasm has been and will continue to be shared with breeders from all countries. Many of the breeders already have availed themselves of the material and now include higher protein as a breeding objective. Many routinely evaluate early generation selections for both yield and protein.

We believe that from this collective effort will come an increasing number of new improved varieties in which high yield, short straw, disease resistance, and other desired agronomic traits are combined with elevated grain protein content and improved nutritional value.

OUTLOOK

Wheat breeding, unlike many other research activities, has no predictable point of termination. Because of the dynamics of wheat production -- particularly associated with diseases and insects that attack wheat -- the effective period of usefulness of new varieties usually is limited to a few years. New disease-resistant productive varieties will not remain so for very many years. Unless there are ongoing breeding programs to generate a continuing flow of new improved varieties, not only will yield advances cease, but realized yields most surely would soon begin to regress.

AID support of the Nebraska project terminated in 1979. With the termination, financial support to assure full exploitation of an enormous amount of improved high protein germplasm and research information ceased.

The research has continued through 1980 with temporary funding from the USDA-SEA-AR, the Nebraska Division of Wheat Utilization and Development, the University of Nebraska, and limited grant funds. Concern exists among IWWPN cooperators in many countries about the future of this valuable international evaluation network and continuation of the international wheat conferences. An effort has been made to establish the IWWPN as a budgeted USDA-SEA activity but to date, has been unsuccessful. Forced termination of this activity for lack of funds would not be in the best interests of U. S. and international agriculture.

STATISTICAL SUMMARY

Project titles and contract numbers:

Improvement of the Nutritional Quality of Wheat through Increased Protein Content and Improved Amino Acid Balance.
Contract No. AID/csd-1208 -- July 1, 1966-March 31, 1974.
A. I. D. funding $1,542,098.17.

Genetic Improvement of Productivity and Nutritional Quality of Wheat.
Contract No. AID/ta-c-1093 -- April 1, 1974-December 31, 1979.
A. I. D. funding $2,012,112.00.

Total A. I. D. expenditures (July 1, 1966-December 31, 1979):
$3,554,210.17.

Principal Investigators:

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PERSONNEL

Name	Period	% Contract Funding
Professionals		
V. A. Johnson	July, 1966 - present	0
P. J. Mattern	July, 1966 - present	50
L. A. Klepper	July, 1972 - March, 1975	100
S. L. Kuhr	September, 1975 - present	100
J. W. Schmidt	July, 1966 - March, 1975	10
J. E. Stroike	July, 1971 - August, 1975	100
R. L. Ulmer	July, 1971 - January, 1974	100
D. A. Whited	February, 1967 - July, 1968	100
K. D. Wilhelmi	August, 1972 - April, 1978	100
Professionals Directing Research Part Time		
M. D. Clegg	April, 1975 - March, 1976	0
L. A. Klepper	" "	0
R. V. Klucas	" "	0
R. A. Olson	" "	0
G. A. Peterson	" "	0
D. H. Sander	" "	0
J. W. Schmidt	" "	0
A. K. Vidaver	" "	0
Technical		
LaToi Aron	March, 1967 - June, 1978	100
Selia Bannerjee	January, 1971 - August, 1972	100
Warren Bennett	September, 1966 - January, 1967	100
James Bishop	May, 1967 - June, 1978	100
Bill Bivin	January, 1967 - January, 1968	100
Kathleen Churchill	March, 1973 - July, 1973	100
Wayne Detmer	May, 1968 - September, 1968	100
Nancy DeVries	August, 1972 - June, 1978	100
Delton Do[illegible]el	January, 1967 - June, 1978	100
Betsy Hancock	March, 1969 - August, 1969	100
	June, 1970 - June, 1978	100
LaVern Hansen	February, 1970 - present	100
Larry Hayne	August, 1969 - June, 1978	100
Carolyn Kappel	June, 1971 - July, 1971	100
Joyce Kovar	September, 1966 - present	100
James Markel	September, 1971 - August, 1972	100
Annette Maybee	October, 1972 - March, 1975	100
Doris Monahan	September, 1966 - July, 1967	100
	October, 1967 - February, 1972	100
Charlotte Pickering	September, 1968 - April, 1971	100
Nancy Rein	February, 1970 - May, 1972	100
Rollin Rolofson	July, 1967 - March, 1968	100
Vernon Shoemaker	September, 1966 - present	100
Edyth Tedefalk	January, 1970 - November, 1970	100
George Volkmer	May, 1967 - October, 1971	100
Linda Zimbelmann	August, 1973 - August, 1974	100

Personnel (concluded).

Dept. of Foods and Nutrition

Professionals

Constance Kies	July, 1971 - March, 1975	0

Technical

Judy Messersmith	March, 1972 - May, 1973	100
Sue Miller	July, 1971 - December, 1971	

BACKGROUND

World population currently stands at approximately 4½ billion people. By the year 2000 it will have reached 6½ billion. Food to nourish this rapidly growing population transcends all other problems confronting countries and governments. The cereals, because they are highly efficient producers of both calories and protein, figure prominently in food production strategies. Wheat and rice are the leading food cereals. More wheat is produced world-wide than rice.

Discovery of major genes in maize that significantly increase the proportion of the limiting essential amino acids lysine and tryptophan in its seed protein raised the question of the existence of similar genetic variation in the other cereals. Genes that increase the amount of protein in wheat had been identified and reported as early as 1962 but nothing was known about possible genetic variation for lysine, the first limiting amino acid in wheat protein.

The Agency for International Development awarded a contract to the University of Nebraska in 1966 to undertake an in-depth investigation of protein content and protein quality of wheat and improve its nutritional value. A second contract was awarded in 1974. Research accomplishments from 1966 to 1976 were contained in four progress reports and in a series of publications and research bulletins.

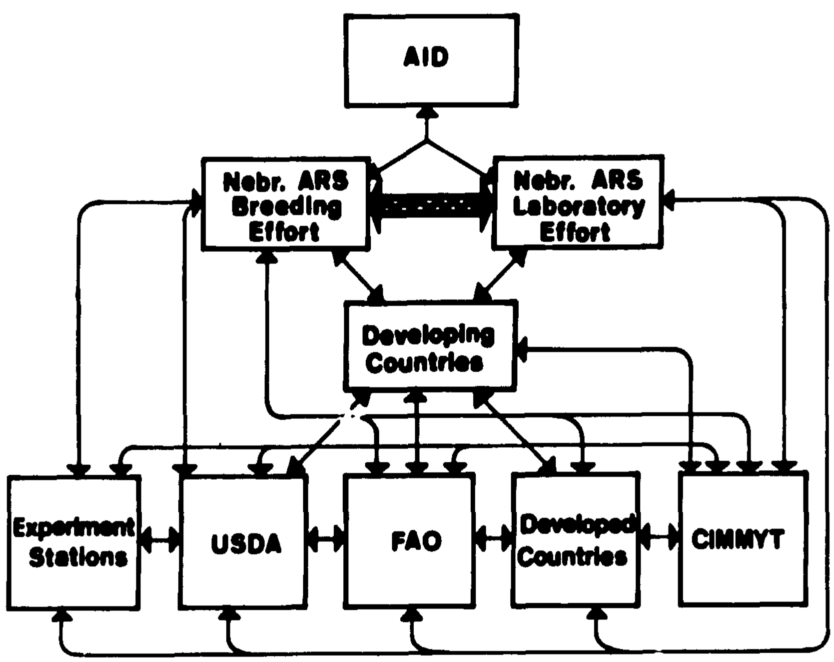
In this final report, research findings for the entire term of the two projects (1966-1979) are summarized and their significance discussed.

COOPERATION

State, federal, and international agencies and organizations have cooperated formally and informally with the University of Nebraska in the research activities of the project on "Genetic Improvement of Productivity and Nutritional Quality of Wheat", Contract Numbers AID/csd-1208 (1966-1974) and AID/ta-c-1093 (1974-1979). Principal formal cooperation has been with USDA-SEA-AR. Financial support for the project has been derived jointly from the Agency for International Development, USDA-SEA-AR, and the University of Nebraska.

Highly effective informal cooperation was established with the International Maize and Wheat Improvement Center (CIMMYT); the Food and Agriculture Organization of the United Nations (FAO); the International Center for Agricultural Research in Dryland Areas (ICARDA); the U. S. State Experiment Stations -- particularly Oregon State University; and wheat research personnel in more than 50 developing and developed countries.

A flow chart of germplasm and information movements outlining the cooperation of the Nebraska project with other agencies and countries is shown.



PROJECT OBJECTIVES

1. Systematically analyze for protein and lysine wheat cultivars in the USDA World Collection including hexaploid, tetraploid, and diploid types and utilize high protein-high lysine cultivars in new hybrid combinations.

2. Develop new productive wheat varieties with improved nutritional quality and evaluate them in appropriate field and laboratory tests.

3. Study the inheritance of protein and lysine in wheat and establish the relationships between protein and lysine and protein and yield.

4. Conduct physical and chemical studies of nutritionally-improved wheats to enable precise characterization of their quality properties and determine nutritional value by small animal and human bioassays.

5. Study nitrogen metabolism and other internal plant processes in wheat to better understand the physiological bases for high productivity and improved nutritional quality.

6. Characterize productivity, performance stability, and nutritional value of new varieties from wheat-producing countries in the International Winter Wheat Performance Nursery to identify superior winter varieties for commercial use and for breeding purposes.

7. Develop and share with developing and developed countries nutritionally-improved wheat germplasm and research information.

8. Provide training in wheat for students from the U. S. and foreign countries and conduct and participate in conferences and workshops for dissemination of new research information.

9. Publish and distribute research results in appropriate technical papers and reports.

RESEARCH ACCOMPLISHMENTS

OBJECTIVE 1

Genetic Variability for Protein and Lysine

Based upon systematic analyses of more than 20,000 wheats in the USDA Collection, substantial genetic variation for grain protein content but only limited genetic variation for lysine is present in Triticum aestivum L. Based on the Nebraska research, genetic variation for protein amounts to 5 percentage points but for lysine per unit protein only 0.5 percentage point (Figure 1).

Protein and lysine variation among wheats in Triticum durum and T. spelta was found to be similar in magnitude as in T. aestivum. Lysine variation among a limited number of wheats in Triticum monoccum also was no greater than in the tetraploid and hexaploid wheats, indicating that the low detectable lysine variation in the polyploid forms is not due to masking of recessive genes for elevated lysine.

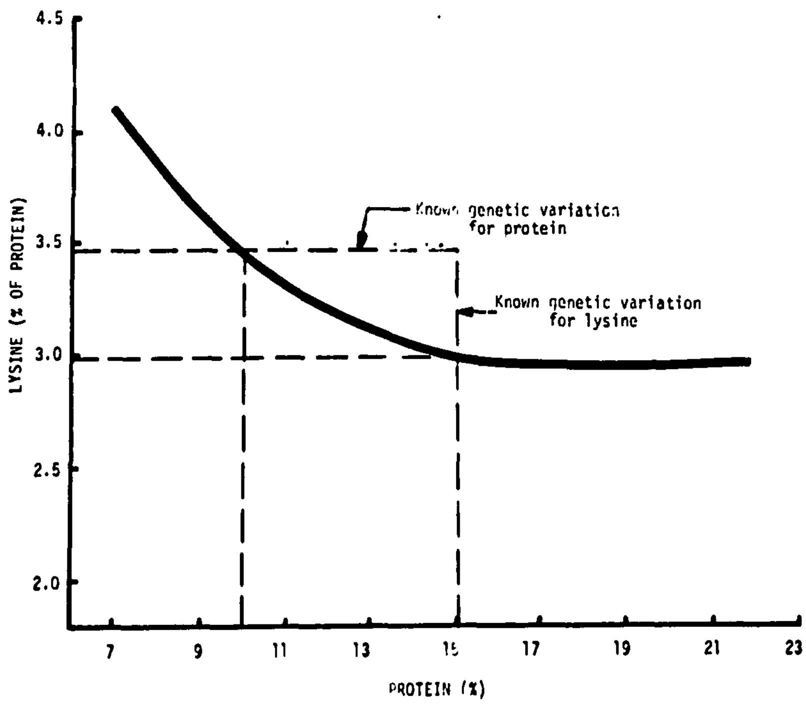


Figure 1. Known genetic variability for protein and lysine in wheat grain should permit development of productive varieties with 5 percentage points higher grain protein and with lysine content equal to that of low-protein varieties.

Genetic Sources of High Protein

Based on evidence from the Nebraska project and from other researchers, many wheats carry genes that affect the level of grain protein. Most of the genes are believed to be minor in their effect on protein and are difficult to identify because of the large and frequently masking effects of environment. Selection for protein as well as yield in early generation hybrid populations can lead to accumulation of such genes and significant increase in protein content of the grain.

The initial and most extensively used genetic source of high protein in the Nebraska project has been Atlas 66. Probably the most is known about the genetic basis for protein in this variety (3, 6, 40, 42).

Nap Hal, an introduction from India, also has been heavily used because of its elevated lysine in addition to high grain protein. Selections higher in protein than either Atlas 66 or Nap Hal have been identified from crosses of the two varieties (45). Their small seed size, generally low productivity and poor agronomic properties required further hybridization with productive agronomically superior varieties. From such crosses, we have been able to identify productive high protein lines with improved agronomic traits. These are being distributed internationally, mainly through a High Protein-High Lysine Observation Nursery assembled annually at Lincoln, Nebraska. It is not likely that any of them will possess the particular combination of traits and adaptation for direct use in developing countries. However, they should be utilized as parents of crosses in each of the countries.

The availability of these wheats should discourage breeders from using such varieties as Atlas 66 and Nap Hal in crosses in the future. A limited number of lines from our project with the best combinations of high protein, yield and other traits are listed in Table 1. All of these and others are available to breeders and agronomists on request. Many are currently in the High Protein-High Lysine Observation Nursery or will be entered in future years.

Table 1. Potentially useful genetic sources of high protein in winter and spring wheats from the Nebraska project.

Plot no.	Pedigree	Growth habit	Type		For protein values and agronomic characteristics see listed tables in text	
79Y132	Favorit/5/Cirpiz/4/Jang Kwang//Atl 66/ Cmn/3/Velvet (NE7060)	W	*T.*	*aestivum*	Table	11
79Y90590	Nap Hal/Atl 66//Lilifen/Krasnodarskaya 39	W	"	"	"	12
79Y90298	Nap Hal/CR8156//F75-71	W	"	"	"	12
79Y90075	Nap Hal/CR8156//Aurora	Int.	"	"	"	12
79Y90421	Nap Hal/Atl 66/Sanja	W	"	"	"	12
79Y90029	Atl 66/Nap Hal//TX62A2522-1-4	W	"	"	"	13
79Y95045	Atl 66/Nap Hal//Norde Desprez 2	W	"	"	"	13
79Y95015	Atl 66/Nap Hal//Lancota/Likafen	W	"	"	"	13
79Y95035	Atl 66/Nap Hal//Skorospelka 35/ NE701137	W	"	"	"	13
79Y95086	Kizombori-1/3/SD69111//NE701136/ Centurk	W	"	"	"	13
79Y95040	Atl 66/Nap Hal//Rousalka/NE701134	W	"	"	"	13
79Y90439	Nap Hal/CI13449//CC-INIA/CNO-7 Cerros	S	"	"	"	12
79Y90313	Timgalen//Nap Hal/Atl 66	S	"	"	"	12
79Y90440	CIMMYT Sel. (Klepper)//Nap Hal/Atl 66	S	"	"	"	12
79Y90065	Nap Hal/Atl 66//F22-70/3/Kavkaz	S	"	"	"	12
79Y90267	CIMMYT Sel. (Klepper)//Nap Hal/Atl 66	S	"	"	"	12
79Y90018	Atl 66/Nap Hal//Skorospelka/NE701137	S	"	"	"	12
79Y90009	"	S	"	"	"	12
79Y92093	Nap Hal/Atl 66//TR535	S	"	"	"	14
79Y92048	Atl 66/Nap Hal//Dwf Bez/Lancota	S	"	"	"	14
79Y92086	Nap Hal/Atl 66//Aurora	S	"	"	"	14

Table 1. (concluded)

Plot no.	Pedigree	Growth habit	Type	For protein values and agronomic characteristics see listed tables in text
79Y90825	Cocorit/CI7517	S	*T. durum*	Table 12
79Y90830	"	S	" "	" 12
79Y90835	"	S	" "	" 12
		CIMMYT Selections (Klepper)		
79Y92005	No. 66/Gallo	S	*T. aestivum*	" 14
79Y92014	(Cal/CC-8156/CNO"S") Cal-Sar, CM-5756-7PY-1PB	S	" "	" 14
79Y92015	"	S	" "	" 14
79Y92016	"	S	" "	" 14
79Y92017	Tob-Turpin/No. 66, CM5214-A-1PY-1PB	S	" "	" 14
79Y92019	"	S	" "	" 14
79Y92020	"	S	" "	" 14
79Y92036	Meng//CNO"S"-No. 66	S	" "	" 14

Genetic Sources of Elevated Lysine

The magnitude of measureable genetic variation in wheat for lysine is, at best, limited. Genes with large effects on lysine level such as the opaque-2 gene in maize have not been found. Small differences in lysine clearly identifiable as genetic effects exist, however. C.I.13449 and Nap Hal exhibit consistently a lysine advantage over other wheats in the range of 0.2 to 0.5 percentage point where lysine is expressed as percent of protein. With careful laboratory measurement techniques this magnitude of difference has been manipulated genetically in the Nebraska project. Since lysine per unit protein is effected by level of protein it is necessary to adjust lysine values to a common protein level for valid comparisons (76, 79).

Both C.I.13449 and Nap Hal have been extensively utilized in crosses with productive spring and winter wheats. C.I.13449, a semi-dwarf experimental winter line from Washington State University, has good yield potential but produces small seed. Nap Hal, a spring habit wheat from the World Collection, also produces small seed and is non-productive. It is a land variety that exhibits substantial variability in morphologic and agronomic traits (Hartmann thesis).

Elevated lysine in wheat has little practical value unless it can be achieved without depression of protein in productive varieties. New experimental lines from the Nebraska project with the most promise as useful genetic sources of elevated lysine are listed in Table 2.

Table 2. Potentially-useful genetic sources of elevated lysine in wheats from the Nebraska project.

Pedigree	Sel. No.	Yield (q/ha)	Protein (%)	Adj.lysine/ protein (%)
		Yuma, Arizona - 1979		
		Triticum aestivum		
Nap Hal/At 66//NS 10-18	90226	53.5	16.9	3.21
Nap Hal/C.I.13449//MV-2	90246	49.5	15.6	3.20
Nap Hal/CR8156//Talent	90247	62.4	14.4	3.29
Nap Hal/C.I.13449//Tob-Turpin/ No. 66	90253	50.7	16.3	3.34
Nap Hal/CR8156//F73-71	90308	55.0	17.1	3.28
Nap Hal/CR8156//NB68719	90532	40.3	16.8	3.30
Nap Hal/Lcr/3/CB96//Nazareth/4/ F73-71	90540	52.3	14.2	3.33
Nap Hal/At 66//Sava	90583	49.6	16.3	3.39
		Triticum durum		
Cocorit/Dabat 119	90705	50.4	15.3	3.32
"	90708	64.5	13.4	3.32
"	90710	57.1	16.7	3.35
Dwf. durum/Cms W. durum/ Libicum/3/P.I.196098	90720	64.6	15.7	3.24
Cocorit/Dabat 134	90734	54.5	15.5	3.41
"	90736	49.1	15.8	3.43
Cocorit/P.I.192086	90769	57.1	16.4	3.34
Cocorit/Dabat 119	90788	63.4	16.3	3.26
Cocorit/Dabat 169	90799	52.3	15.8	3.31
Cocorit/C.I.7267	90837	60.9	15.4	3.20
		Yuma, Arizona - 1978		
		Triticum aestivum		
Nap Hal/At 66//TR535	10868	34.4	18.8	3.24
Kiz-1/3/SD69111//NE701136/ Centurk	11235	43.9	16.4	3.25
GK-Fertodi 2/NE701134	11237	44.3	17.0	3.18
Skorospelka 35//Nap Hal/ C.I.13449	11284	35.9	17.7	3.21
Blueboy II//Nap Hal/C.I.13449	11286	62.5	14.8	3.37
Nap Hal/C.I.13449//Hyslop	11368	29.7	15.9	3.18
Nap Hal/C.I.13449/3/TR535// Nap Hal/Lcr	11380	35.0	16.6	3.23
F50-71//Nap Hal/C.I.13449	11391	46.3	15.9	3.28
Nap Hal/C.I.13449//Centurk	11479	38.1	14.8	3.20
Nap Hal/C.I.13449	50205	30.0	17.2	3.37
At 66/Nap Hal//Rousalka/ NE701134	50263	41.3	16.4	3.24
At 66/Nap Hal//Carifen 12	50277	33.6	16.6	3.32

OBJECTIVE 2

Breeding Advances and Variety Development

Research at the University of Nebraska to increase the protein content of wheat initially utilized Atlas 66 as the main genetic source of high protein. Because Atlas 66 is a soft wheat with no winterhardiness, two cycles of breeding, ie/ (Atlas 66/Comanche)// Lancer, were required for the development of the high protein hard winter variety Lancota which was released jointly by the USDA, Nebraska, South Dakota, Kansas, and Texas in 1975 (34). Lancota combines excellent yield potential with elevated grain protein content, good milling and baking properties, moderate resistance to leaf and stem rust, intermediate reactions to the wheat streak mosaic virus and Septoria leaf blotch, and good winterhardiness.

The performance of Lancota in Nebraska trials is compared with the popular Centurk and Scout 66 varieties in Table 3. It was comparable in yield to both varieties and had a protein advantage of approximately 1.5 percentage point in statewide trials in 1973 and 1974 (60).

Table 3. Performance of "Lancota" winter wheat in Nebraska state-wide trials in 1973 and 1974.

Variety	Grain yield (q/ha)			Protein content[1] (%)		
	1973	1974	2-yr. av.	1973	1974	2-yr. av.
Lancota	28.6	32.6	30.6	15.5	15.0	15.3
Centurk	29.3	32.6	31.0	13.9	13.7	13.8
Scout 66	29.3	31.3	30.3	13.9	13.8	13.9

[1]Dry weight basis

Lancota was compared with Centurk at Lincoln, Nebraska in 1976 in 16 paired plots (Table 4) (60). It was consistently slightly more productive and produced grain with approximately 2% higher protein than Centurk.

Table 4. Grain yield and protein content of Centurk and Lancota winter wheat varieties in paired plot comparisons at Lincoln, Nebraska, 1975.

Centurk				Lancota			
Protein	Lysine		Yield	Protein	Lysine		Yield
	Adj.	Unadj.			Adj.	Unadj.	
%	%	%	q/ha	%	%	%	q/ha
15.3	3.3	3.1	40.7	16.6	3.0	2.8	45.7
15.6	3.1	2.9	36.2	17.6	2.9	2.7	40.8
16.1	3.1	2.9	37.0	17.8	2.9	2.6	37.7
16.1	3.1	2.9	33.8	17.1	2.9	2.7	38.0
16.1	3.0	2.9	34.1	17.9	2.9	2.7	33.5
15.3	3.2	3.0	36.6	17.9	2.9	2.7	39.2
15.9	2.9	2.7	33.2	17.4	2.9	2.7	38.2
15.4	3.2	3.0	35.2	17.1	2.9	2.7	35.2
16.0	2.8	2.6	35.3	17.7	3.0	2.8	34.9
15.8	3.2	3.0	32.4	17.7	2.9	2.7	28.9
15.3	3.3	3.1	38.3	16.7	3.0	2.8	43.0
15.6	3.2	3.0	35.6	17.7	2.9	2.6	37.3
15.0	3.1	3.0	37.9	17.3	2.8	2.5	40.0
15.6	3.2	3.0	38.8	17.6	2.9	2.7	36.5
14.9	3.0	2.9	37.6	17.8	2.9	2.7	38.7
15.2	3.2	3.1	42.9	17.7	2.8	2.6	39.9
16.2	3.1	2.9	34.7	17.6	2.7	2.5	37.3
15.6	3.2	3.0	25.2	17.5	2.9	2.7	29.9
$\bar{x}$=							
15.6	3.1	2.9	35.9	17.5	2.9	2.7	37.5

Lancota was tested for 3 years in the hard red winter wheat Southern Regional Performance Nursery grown in 13 states of central United States (30). Its yield and protein content relative to other experimental varieties and the Kharkof check variety are shown in Figure 2. It can be seen that the protein content of Lancota remained somewhat higher than Kharkof despite its very large yield advantage over Kharkof. Lancota also was higher yielding than other experimental varieties on the average, and produced grain with approximately 1 percentage point higher protein. Because of its combined advantage over other experimental varieties in both yield and protein, the protein production of Lancota was substantially higher than other varieties in the nursery (Figure 3).

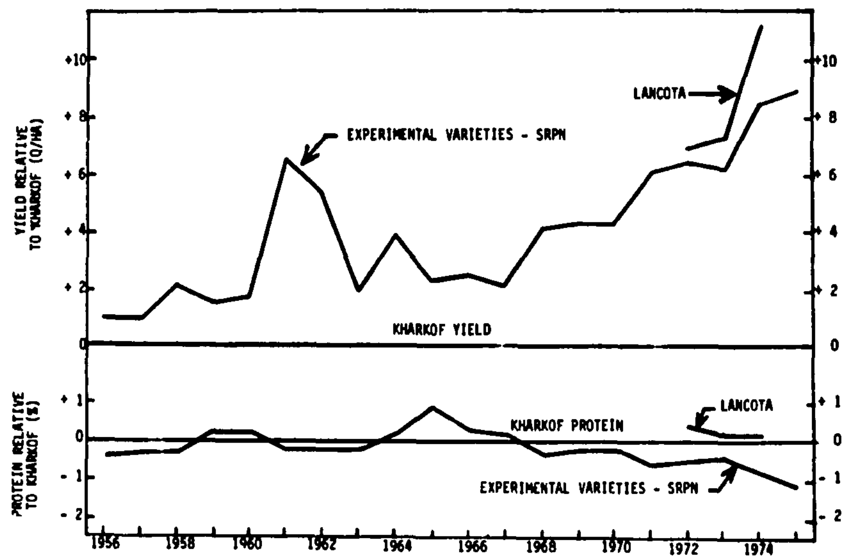


Figure 2. Annual mean yields and protein content of experimental varieties grown in the Southern Regional Performance Nursery in relation to the Kharkof check variety, 1956-1975.

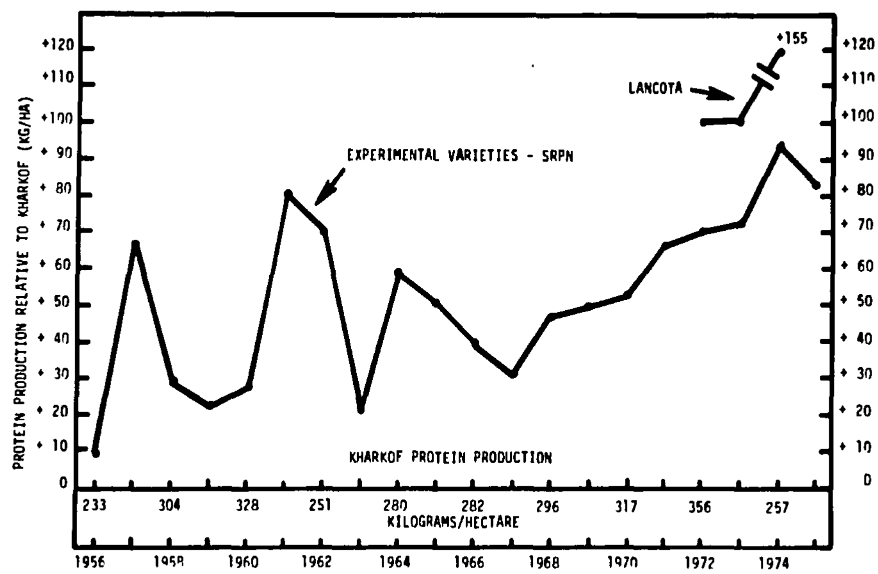


Figure 3. Annual protein production per acre of experimental varieties grown in the Southern Regional Performance Nursery compared with the Kharkof check variety, 1956-1975.

Lancota was evaluated in the International Winter Wheat Performance Nursery in 1972 and 1973 (77, 80). In Table 5 its grain protein is compared over 25 test sites with four other varieties whose yields were comparable with Lancota. Its protein advantage over these varieties ranged from 1.1 to 2.3 percentage points.

Table 5. Performance of Lancota in the International Winter Wheat Performance Nursery in 1972 and 1973 (25 test sites).

Variety	Average yield (q/ha)	Average protein content (%)
Lancota	40.7	15.5
Zenith	39.7	14.4
Centurk	43.9	14.0
TAM 102	39.9	13.5
Maris Nimrod	43.4	13.2

An Atlas 66-derived experimental line from Nebraska also was utilized in the German Democratic Republic in the development of a new experimental variety that combines yield as high or higher than the leading variety Alcedo, and grain protein content 1 to 2 percentage points higher than Alcedo. The new variety was in state trials in 1979 in the GDR but it is not known whether it has been approved for registration.

With the identification of Nap Hal as a potentially useful genetic source for both high protein and elevated lysine, and C.I.13449 as an elevated lysine source, crosses were made between them and with Atlas 66 to study genetic relationships among the varieties and determine whether protein and lysine could be increased above the levels of the parent varieties (45). The low winterhardiness of the parents necessitated propagation, selection, and testing in winter nurseries at Yuma, Arizona.

The performance of six lines selected from Nap Hal/Atlas 66 is shown in Table 6 (92). The lines produced grain with protein content significantly higher than either parent and 4 to 7 percentage points higher than the Centurk check variety. Their grain yield, however, was only intermediate to the parents and substantially lower than that of Centurk. Their lysine was intermediate to the parents. Clearly, the lines possessed genetic potential for very high protein but, because of low productivity, had value only for breeding purposes.

Lines selected from the cross Nap Hal/C.I.13449, in contrast to the Nap Hal/Atlas 66 lines, were highly productive under irrigation at Yuma, Arizona as was the C.I.13449 parent (Table 7) (92).

Table 6. Performance of Nap Hal/Atlas 66 lines in a replicated 1975 high protein-high lysine wheat nursery, Yuma, Arizona.

Entry	Protein (%)	Adjusted lysine per unit protein (%)	Yield (q/ha)
Nap Hal	14.7	3.3	27.4
Atlas 66	14.9	3.1	44.5
Centurk	11.7	3.1	55.0
Nap Hal/At 66 292	19.0	3.1	35.7
" 297	17.8	3.2	32.9
" 232	17.8	2.9	43.1
" 296	17.6	3.2	34.9
" 285	17.0	3.2	33.2
" 185	16.1	3.2	35.7
$LSD_{.05}$	1.3	0.1	15.3

Table 7. Performance of Nap Hal/C.I.13449 lines in the 1975 Yuma high protein-high lysine wheat nursery.

Entry	Protein (%)	Adjusted lysine per unit protein (%)	Yield (q/ha)
Nap Hal	14.7	3.3	27.4
C.I.13449	10.9	3.3	67.8
Centurk	11.7	3.1	55.0
Nap Hal/C.I.13449 248	13.3	3.3	63.6
" 245	12.9	3.6	70.4
" 305	12.7	3.5	57.2
" 253	12.5	3.4	87.5
" 247	12.2	3.5	71.0
" 205	12.2	3.5	65.5
$LSD_{.05}$	1.3	0.1	15.3

Of the six lines shown three were higher yielding than C.I.13449 and all were higher yielding than the Centurk check variety. Despite their enormous yield advantage over the non-productive Nap Hal parent they were intermediate to the parents in protein content and significantly higher than C.I.13449 and Centurk. All were equal to or higher in adjusted lysine than C.I.13449.

Several of the experimental lines from each cross were evaluated in observation nurseries at 11 sites in 10 countries in 1975 (84).

Consistent with their performance at Yuma the Nap Hal/Atlas 66 lines produced grain with very high protein content and with lysine (adjusted) equal to that of Centurk (Table 8). The Nap Hal/C.I.13449 lines were somewhat lower in protein than the Nap Hal x Atlas 66 lines but significantly higher in both protein and lysine than Centurk. Since grain yields are not known, the protein and lysine values from the international sites must be considered with caution. However, performance of the lines in the replicated trial at Yuma suggests that the protein and lysine values from international sites reflect true genetic differences.

Table 8. Average protein and lysine content of selected high protein-high lysine experimental lines grown at 11 test sites in 10 countries in 1975.

Variety or Pedigree	Plot no.	Protein: %	Lysine % of protein
Centurk	$\bar{x}$ of 2 plots	14.3	3.0
Nap Hal/At 66	219	17.5	3.0
"	180	17.5	3.0
"	220	16.9	3.0
Nap Hal/C.I.13449	171	16.8	3.2
"	194	16.4	3.2
"	173	16.2	3.2
"	207	16.0	3.2
$LSD_{.05}$		1.2	0.11

Perhaps the most promising high protein lines were selected at Lincoln from the complex cross Favorit/5/Cirpiz//Jang Kwang/4/Atlas 66/Comanche/3/Velvet (27). In unreplicated plots at Lincoln in 1975 they exhibited high grain production and high protein potential combined with short plant height, excellent seed and good dough-mixing properties (Table 9). Additionally, the lines possess good winterhardiness and excellent field resistance to leaf and stem rusts and mildew based on evaluation in the IWWPN under the designation NE7060.

The performance of the lines in a replicated trial at Yuma, Arizona in 1976 is shown in Table 10. Most were comparable in yield with Centurk, Lancota, and C.I.13449 but produced much larger seed with higher protein content than the check varieties and with comparable adjusted lysine content.

Table 9. Promising high protein experimental winter wheats grown in unreplicated plots at Lincoln, Nebraska in 1975.

Pedigree or name	Plot no.	Plant height (cm)	Seed rating[1]	Grain yield (q/ha)	Grain protein content (%)	Mixing Time (min)	Mixing Tolerance
Centurk (check)	$\bar{x}$ of 18 plots	102	G	35.9	15.6	3-2/3	4
Lancota (check)	"	97	VG	37.5	17.5	3-1/3	3
Favorit/5/Cirpiz// Jang Kwang/4/At 66/ Cmn/3/Velvet	11345	86	VG	39.6	19.1	3-2/3	4
"	12288	84	VG	41.4	18.9	3	4
"	12291	81	G-VG	41.0	19.8	3-2/3	4
"	12293	84	VG	41.1	19.3	3-2/3	4
"	12297	81	VG	42.0	19.1	3	3+
"	12312	81	VG	39.0	19.1	4	4
"	12327	86	VG	41.0	18.7	4	4
"	12332	84	VG	41.6	18.9	4	4-
"	12335	86	Exc.	41.9	18.5	4	4-

[1]G, VG, and Exc. = good, very good, and excellent, respectively.

Table 10. Performance of promising new high protein lines evaluated in duplicate nursery plots at Yuma, Arizona in 1976.

Variety or Pedigree	Plot number	Yield	100-kernel weight	Protein	Lysine (% of protein)	
					Unadj.	Adj.
		q/ha	g	%	%	%
Centurk	$\bar{x}$ of 14 plots	54	3.6	11.6	3.3	3.2
Lancota	"	45	3.7	12.9	3.2	3.2
C.I.13449	"	50	3.1	12.1	3.3	3.4
Favorit/Cirpiz/ Jang Kwang/At 66/ Comanche/Velvet	343	51	4.5	14.3	3.2	3.3
"	436	48	4.5	14.3	3.2	3.3
"	437	48	4.5	14.6	3.1	3.2
"	439	49	4.6	14.2	3.2	3.3
"	444	51	4.6	14.1	3.2	3.4
"	457	50	4.3	14.3	3.1	3.2
"	459	49	4.6	14.6	3.0	3.2
"	460	54	4.5	14.2	3.0	3.1
$LSD_{.05}$		12.3	--	--	--	--

The performance of lines from NE7060 in a High Protein-High Lysine Observation Nursery at 7 international sites in 1976 and 6 sites in 1977 from which grain yields were recorded is compared with other experimental lines and check varieties in Figures 4 and 5. The NE7060 lines were comparable to Bezostaya 1 in yield, more productive than C.I.13449, but generally less productive than Centurk and Lancota in 1976. In 1977 the NE7060 lines were similar to these varieties in yield. However, in both years the lines of NE7060 were consistently among the highest in grain protein content.

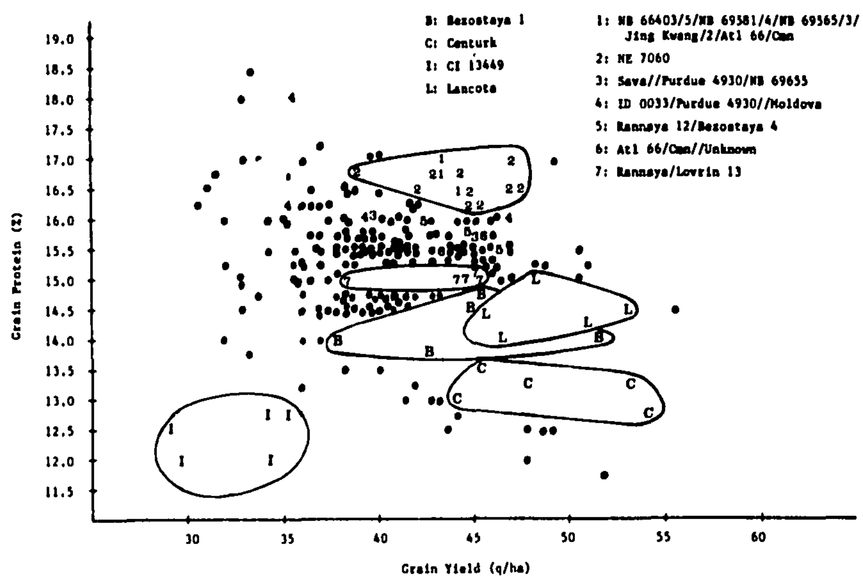


Figure 4. Grain protein content versus grain yield for entries in the second high protein-high lysine winter wheat observation nursery averaged over seven sites in 1976.

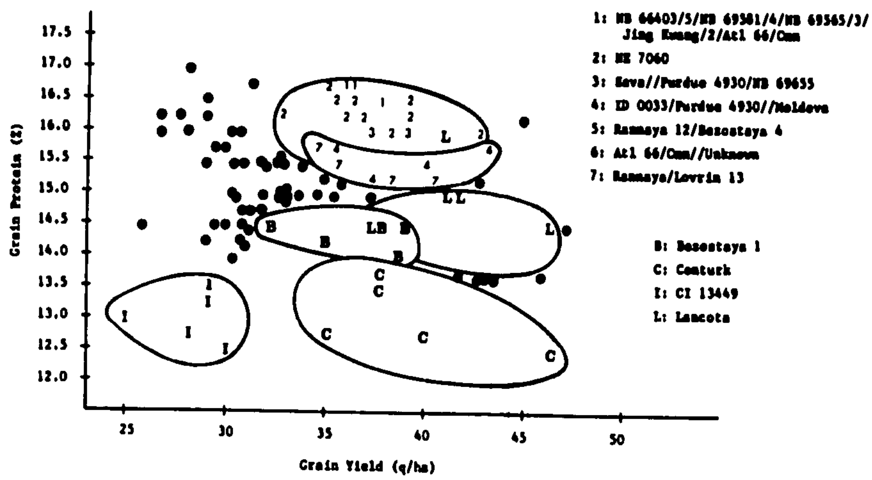


Figure 5. Grain protein content versus grain yield for entries in the third high protein-high lysine winter wheat observation nursery averaged over six sites in 1977.

The relationship of lysine (% of protein) to protein among the lines and varieties tested internationally in 1976 and 1977 is shown in Figures 6 and 7.

The negative correlation of lysine and protein up to 15% protein is evident. It is noteworthy that lines of NE7060 were as high in lysine as Bezostaya and Lancota despite being much higher in protein content, showing that there is little or no relationship of protein and lysine at protein levels above 15%.

The lines from NE7060 are being extensively utilized in Nebraska, Yugoslavia, and elsewhere for breeding purposes because of their combination of high protein potential, large seed, winterhardiness, and disease resistance. They also refute the erroneous idea that elevated protein results from small or shrivelled seed and is not compatible with large seed size.

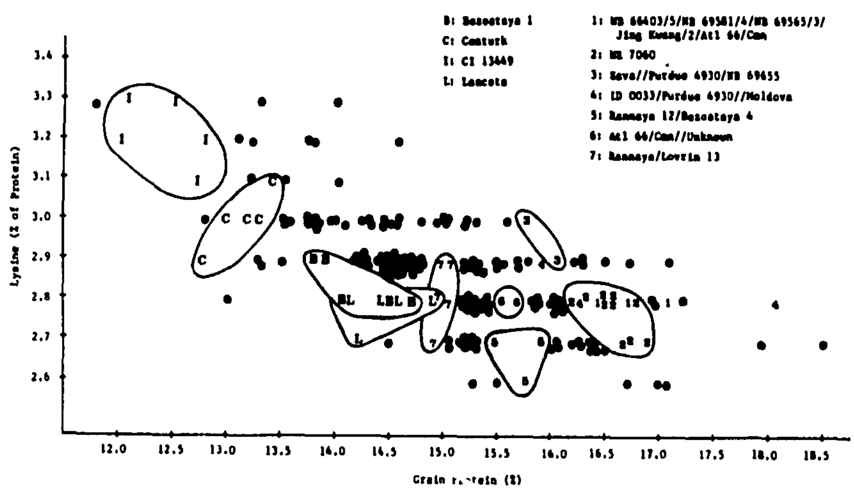


Figure 6. Lysine (% of protein) versus grain protein content for entries in the second high protein-high lysine winter wheat observation nursery averaged over seven sites in 1976.

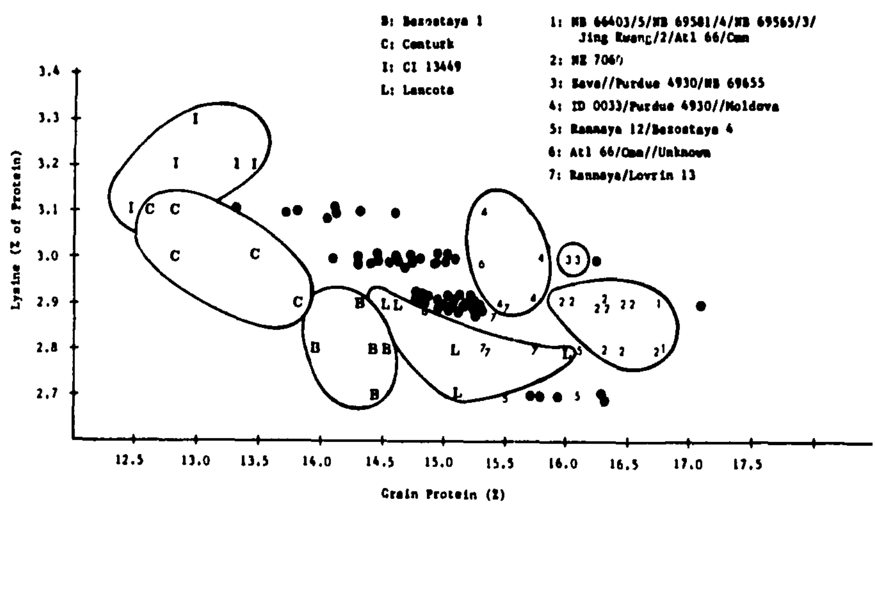


Figure 7. Lysine (% of protein) versus grain protein content for entries in the third high protein-high lysine winter wheat observation nursery averaged over six sites in 1977.

Another group of materials with excellent potential value for elevation of protein content combined with high productivity comes from selections made by L. Klepper among populations of semi-dwarf spring wheat in Mexico. Dr. Klepper had begun a selection program for elevated protein while an employee of CIMMYT. Upon joining the Nebraska project he brought with him the selections with the best promise. These were reselected at Yuma and evaluated for yield and protein (66). Nineteen different CIMMYT populations are represented in Figure 8. Most of the lines were less productive than Super X. A few were equal to Super X in yield. All of the lines ranged from 2 to 7 percentage points higher than Super X in protein content. Although the yield of Super X varied widely among its 12 plots in each replication, its protein content among the plots remained essentially unchanged.

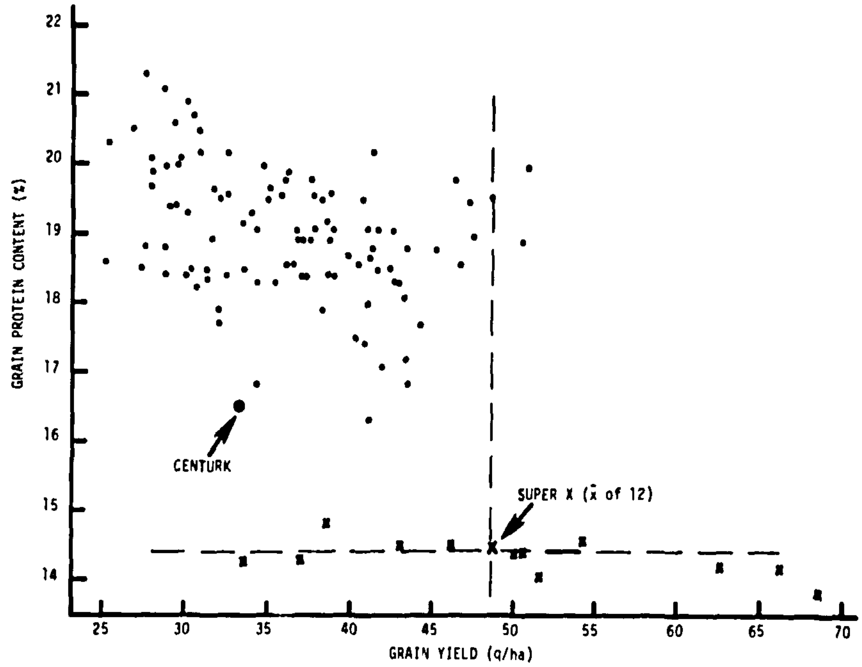


Figure 8. Relationship of grain yield and grain protein content among lines selected by L. Klepper for high protein in 19 CIMMYT spring wheat populations. Data are from a replicated yield nursery grown at Yuma, Arizona in 1978.

These results are interpreted as evidence of numerous genes for protein in wheat and point to the opportunity to increase protein content of high yielding wheat by selection for protein as well as for yield in early generations of the breeding program.

The best of the lines from Nap Hal/Atlas 66, Nap Hal/C.I.13449, NE 7060, and the CIMMYT selections have been utilized heavily in various hybrid combinations and with productive winter wheats -- particularly semi-dwarf types from Eastern Europe and the USA to improve productivity and agronomic worth. Particular attention was given to improvement of seed size in the lines derived from C.I.13449 and Nap Hal, both of which produce small seed, and to the reduction of plant height.

The yield and protein content of moderately winterhardy winter lines in a replicated nursery at Yuma in 1978 are plotted in Figure 9; and for non-hardy winter and spring lines in Figure 10 (66). It can be noted that many of the winterhardy lines were equally as productive or more productive than Centurk and most were from 1 to 3% higher than Centurk in protein content. The nonhardy winter lines and spring lines were predominantly higher than Centurk in protein content and approximately one-half of them were equal to or higher yielding than Centurk.

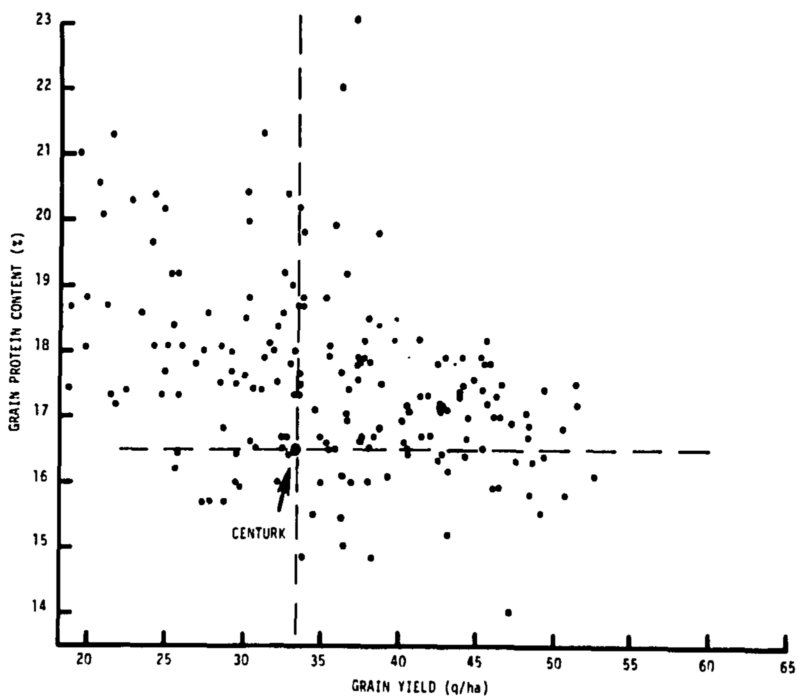


Figure 9. Relationship of grain yield and grain protein content among moderately winter hardy experimental wheats selected for high protein and/or high lysine and grown in a replicated yield nursery at Yuma, Arizona, in 1978.

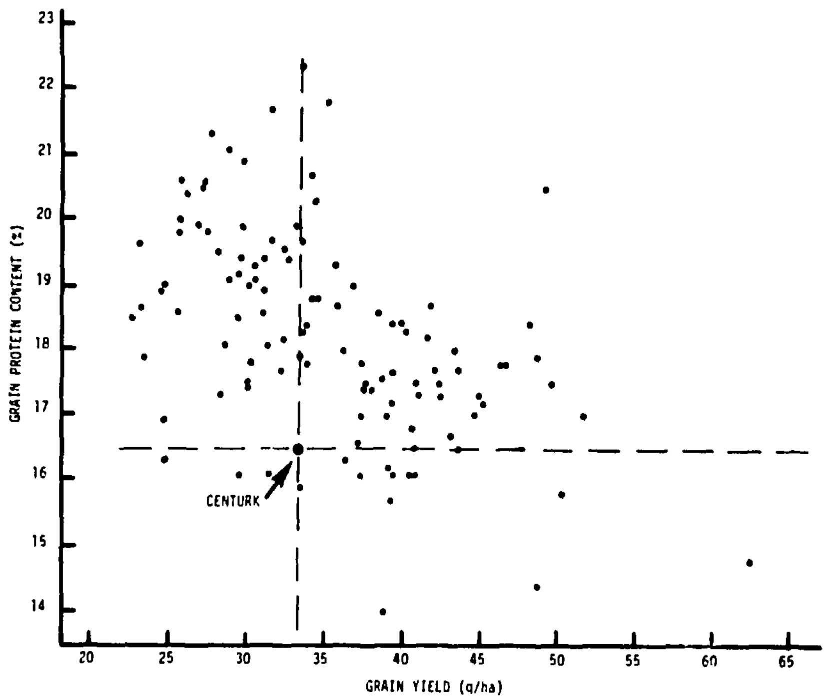


Figure 10. Relationship of grain yield and grain protein content among spring and nonhardy winter wheats selected for high protein and/or high lysine and grown in a replicated yield nursery at Yuma, Arizona, in 1978.

In 1979 85 lines with the best prior records for protein were evaluated in an "elite" nursery at Yuma. Also 306 lines from the third breeding cycle involving crosses of high protein selections with semidwarf European and U. S. wheats and CIMMYT selections were evaluated in a replicated nursery. The performance of selected lines in each nursery is summarized in Tables 11 and 12. Many of the lines included in Table 12 possess attractive combinations of high productivity with exceptionally high grain protein content and short straw. The average yield of the 308 best new lines harvested in this nursery was 45.8 q/ha, an advance of 5 q/ha over the average yield of the older lines tested in the "elite" nursery (Table 11). The average protein content of harvested lines in each nursery was the same at 17.2%.

The 3-year average yield performance (1977-1979) of the most promising winter lines at Yuma together with their protein values in 1977 and 1978 are shown in Table 13. The 1979 protein determinations have not yet been made. Most of the lines were much more productive than Centurk, Lancota, and C.I.13449 and were as high as or higher in protein content than Lancota on the average.

A similar 3-year performance record of promising spring wheat high protein lines is summarized in Table 14. The combined high yields and high protein contents of the Klepper selections from CIMMYT wheats are particularly noteworthy.

Table 11. Performance of selected "elite" lines (based on protein data from prior years at Lincoln, Nebraska and Yuma, Arizona) in a replicated nursery grown under irrigation at Yuma, Arizona in 1979.

Entry no.	Name or pedigree	Maturity	Plant height	Yield (q/ha)	Protein content (%)	Adjusted lysine/protein (%)
43	Jinkwang//Atlas 66/Comanche	late	med.	56.4	18.5	2.9
41	"	late	m. tall	55.6	18.0	2.9
53	Nap Hal/CR8156	late	m. sh.	55.4	17.3	3.0
61	CIMMYT Selection (Klepper)	m. ea.	sh.	54.8	18.9	2.7
—	Super X (check)	ea.	sh.	49.6	13.9	2.8
40	Jinkwang//Atlas 66/Comanche	late	m. tall	47.0	18.3	3.1
32	Favorit/5/Cirpiz//Jang Kwang/4/At 66/ Cmn/3/Velvet (NE7060)	m. late	med.	46.9	18.1	2.9
33	" " (NE7060)	m. late	med.	45.9	18.1	2.9
37	Sava//Purdue 4930/NB69655	med.	m. tall	45.7	18.4	2.7
—	Centurk	med.	med.	40.3	15.6	2.9
—	Lancota	late	m. tall	40.0	17.2	2.9
	Nursery $\bar{x}$ (N=85)	-	-	40.8	17.2	2.9
	$LSD_{.05}$			12.9	1.0	0.26
	CV(%)			15.8	3.0	4.4

Correlation coefficient: Yield vs. protein = -0.04; protein vs. lysine = -0.27.

Table 12. Performance of selected high protein lines in a replicated nursery grown under irrigation at Yuma, Arizona in 1979.

Plot no.	Name or pedigree	Growth habit 1/	Maturity 2/	Plant height 3/	Yield (q/ha)	Protein content (%)	Adjusted lysine/protein (%)
435	Nap Hal/CR8156//Talent	S	M	Sh.	80.3	14.5	3.0
576	Nap Hal/CR8156//Tx62A4793-7/NB66403	W	M	Sh.	65.1	14.9	3.0
439	Nap Hal/C.I.13449//CIMMYT Selection	S	ME	Sh.	57.9	18.5	2.8
830	Cocorit/C.I.7517 (Spring durum)	S	L	M. sh.	56.7	17.3	2.8
590	Nap Hal/At 66//Lilifen/Krasnodar-skaya 39	W	L	M. sh.	53.7	18.5	2.7
835	Cocorit/C.I.7517 (Spring durum)	S	L	Sh.	53.2	17.4	3.0
825	"	S	E	Sh.	51.5	18.2	3.0
313	Timgalen//Nap Hal/At 66	S	E	M. sh.	49.7	18.6	2.8
440	CIMMYT Sel.//Nap Hal/At 66	S	ML	Sh.	49.7	17.5	2.8
298	Nap Hal/CR8156//F75-71	W	ME	Sh.	49.6	18.9	3.0
65	Nap Hal/At 66//F22-70/3/Kavkaz	S	M	M. sh.	49.3	18.5	2.6
75	Nap Hal/CR8156//Aurora	I	ME	Med.	49.1	18.4	2.9
—	Centurk (check)	W	M	Med.	48.8	15.6	2.9
194	Nap Hal/C.I.13449//NS12-56	W	ME	Med.	48.5	17.6	2.8
267	CIMMYT Sel.//Nap Hal/At 66	S	ME	Sh.	48.2	18.0	3.1
—	Super X (check)	S	E	Sh.	48.2	14.2	3.0
18	At 66/Nap Hal//Skorospelka/NE701137	S	E	Sh.	47.9	19.2	3.0
589	Nap Hal/At 66//Lilifen/Krasnodar-skaya 39	W	L	Med.	47.2	18.7	2.7
421	Nap Hal/At 66//Sanja	W	ME	Sh.	47.2	18.4	2.9
9	At 66/Nap Hal//Skorospelka/NE701137	S	ME	M. sh.	47.0	20.9	2.8
—	Lancota (check)	W	L	Tall	42.2	17.0	2.9
	Nursery $\bar{x}$ (N = 306)	-	-	-	45.8	17.2	
	$LSD_{.05}$				12.2	—	
	CV (%)				13.5		

1/ S=spring; W=winter; I=intermediate or segregating. 2/ M=medium; ME=mod. early; E=early; L=late; ML=mod. late. 3/ Sh=short; M.sh.=mod. short; med=medium.
Correlation coefficient: Yield vs. protein= -0.55; protein vs. lysine= -0.55.

Table 13. Performance of selected high protein winter wheat lines from 1977 to 1979 under irrigation at Yuma, Arizona.

Entry no.	Name or pedigree	Maturity 1979	Plant height 1979	Yield (q/ha) 1977	Yield (q/ha) 1978	Yield (q/ha) 1979	Yield (q/ha) $\bar{x}$	Protein (%) 1977	Protein (%) 1978	Protein (%) $\bar{x}$	Adj. lysine/ protein (%) 1977
5	At 66/Nap Hal//NB68570/ Centurk	m.late	m.sh.	78.7	51.2	49.9	59.9	16.4	17.5	16.9	2.7
21	At 66/Nap Hal// TX62A2522-1-4	"	short	65.8	45.8	57.8	56.5	15.8	17.8	16.8	2.9
20	"	"	"	62.3	42.8	59.4	54.8	16.1	17.9	17.0	2.9
18	"	late	"	71.7	46.0	45.4	54.4	16.8	17.3	17.0	2.8
19	"	"	"	70.2	45.5	47.1	54.3	15.8	18.2	17.0	2.9
8	"	m.late	m.sh.	78.5	37.3	45.2	53.7	16.4	17.9	17.1	3.0
29	"	late	short	64.6	45.2	50.3	53.4	17.7	17.8	17.7	2.9
27	"	"	"	47.1	51.3	57.0	51.8	16.4	17.2	16.8	2.9
30	"	"	"	51.5	46.6	57.3	51.8	16.2	17.5	16.8	2.9
45	At 66/Nap Hal// Norde Desprez 2	m.late	"	71.2	39.8	53.6	54.9	15.9	18.4	17.1	2.9
15	At 66/Nap Hal//Lancota/ Likafen	late	"	78.0	41.7	41.5	53.7	17.0	17.3	17.1	2.9
14	"	"	"	74.1	37.2	42.1	51.1	16.6	17.6	17.1	2.9
16	"	"	"	66.3	36.5	49.5	50.8	16.9	17.4	17.1	2.9
40	At 66/Nap Hal//Rousalka/ NE701134	med.	"	71.6	35.2	53.6	53.5	16.2	17.9	17.0	3.0
35	At 66/Nap Hal// Skorospelka/NE701137	m.late	med.	73.7	33.7	52.1	53.2	17.1	19.8	18.4	3.0
34	"	"	"	49.0	49.1	43.8	47.3	18.3	20.5	19.4	2.8
33	"	"	"	44.0	36.1	44.5	41.5	18.6	22.1	20.3	2.8

Table 13. (concluded)

Entry no.	Name or pedigree	Maturity 1979	Plant height 1979	Yield (q/ha) 1977	Yield 1978	Yield 1979	Yield $\bar{x}$	Protein (%) 1977	Protein 1978	Protein $\bar{x}$	Adj. lysine/protein (%) 1977
86	Kiz-1/3/SD69111//NE701136/Centurk	m.late	m.sh.	59.8	43.8	49.5	51.0	16.8	17.3	17.0	2.8
65	Nap Hal/At 66//Sort 12-13	m.ea.	short	57.2	33.4	39.8	43.5	20.7	20.2	20.4	2.8
--	Super X (spring check)	early	"	--	52.9	65.4	59.1[1]	—	14.5	14.5[2]	---
—	Lancota (check)	late	tall	48.6	37.2	38.7	41.5	16.3	17.8	17.0	---
—	C.I.13449 (check)	"	short	42.5	--	34.5	38.5[1]	14.4	—	14.4[3]	---
—	Centurk (check)	med.	med.	31.2	29.7	—	30.5[1]	16.8	16.6	16.7	---
$\bar{x}$ All entries excluding check varieties				—	—	--	46.3	--	--	17.3	---
$LSD_{.05}$				--	--	--	11.8	--	--	1.2	---
CV(%)				—	—	—	15.9	--	--	3.6	---

[1] Mean value based on two years only.
[2] Value from 1978 only.
[3] Value from 1977 only.

Table 14. Performance of selected high protein spring wheat lines from 1977 to 1979 under irrigation at Yuma, Arizona.

Entry no.	Name or pedigree	Maturity 1979	Plant height 1979	Yield (q/ha) 1977	Yield (q/ha) 1978	Yield (q/ha) 1979	Yield (q/ha) x̄	Protein (%) 1977	Protein (%) 1978	Protein (%) x̄	Adjusted lysine/protein 1977 (%)
17	CIMMYT Sel. (Klepper)	M. ea.	Short	70.6	48.8	51.9	57.1	18.7	19.6	19.1	2.8
15	" " "	Early	"	63.2	46.7	60.7	56.9	17.8	18.6	18.2	2.9
14	" " "	"	"	58.0	50.6	58.1	55.6	18.8	18.9	18.8	2.8
19	" " "	M. ea.	"	63.4	47.4	52.6	54.5	18.8	19.0	18.9	2.9
36	" " "	" "	M. sh.	61.7	51.0	49.5	54.1	20.5	20.0	20.3	2.8
20	" " "	" "	Short	61.0	46.4	50.3	52.6	18.8	19.8	19.3	2.9
5	" " "	Early	"	57.9	45.2	54.2	52.4	18.0	18.8	18.4	3.1
16	" " "	"	"	58.5	42.7	55.2	52.1	19.0	19.1	19.0	2.8
--	Super X (check)	M. ea.	"	--	52.9	65.4	59.1[1/]	--	14.5	14.5[2/]	---
93	Nap Hal/At 66//TR535	M. late	M. sh.	69.8	49.5	46.5	55.3	17.0	17.5	17.3	3.1
95	"	Med.	"	65.0	48.0	46.7	53.2	17.1	18.4	17.7	3.1
48	At 66/Nap Hal//Dwf. Bez./ Lancota	"	Short	62.6	41.4	44.4	49.5	17.4	18.2	17.8	3.0
86	Nap Hal/At 66//Aurora	M. ea.	M. sh.	52.7	36.7	45.9	45.1	19.3	19.0	19.1	2.9
54	At 66/Nap Hal//NE701152/ Aurora	Med.	" "	53.6	31.5	43.1	42.7	18.5	19.7	19.1	2.9
77	Nap Hal/At 66//Likafen/ At 66/Cmn/Hume	M.late	" "	57.6	31.4	38.8	42.6	19.2	18.1	18.6	2.9
--	Lancota (check)	Late	Tall	47.5	37.2	39.4	42.7	15.8	17.8	16.0	---
--	C.I.13449 (check)	"	Short	42.5	--	34.3	38.4[3/]	14.4	--	14.4[4/]	---
	x̄ All entries excluding check varieties			--	--	--	42.5	--	--	18.5	---
	$LSD_{.05}$ " " "			--	--	--	10.2	--	--	1.4	---
	CV(%)			--	--	--	15.0	--	--	3.9	---

1/ x̄ value based on 2 years only. 2/ Value from 1978 only. 3/ x̄ value based on 2 years only. 4/ Value from 1977 only.

OBJECTIVE 3

Inheritance of Protein and Lysine

Crosses of Atlas 66 x Nap Hal produce progenies that show transgressive segregation for high and low protein, indicating that the parent varieties carry different genes for protein. Similar transgressive segregation for lysine per protein was detected in the cross Nap Hal x C.I. 13449 (45, 56, 60).

Atlas 66 possesses at least two genes for elevated grain protein. One of the genes is linked closely with a gene for adult leaf rust resistance. Cytogenetic studies using chromosome substitutions indicate that Atlas 66 chromosome 5D carries a major gene(s) for protein content and 5A a gene(s) with less effect. It has not been determined which of the two chromosomes has the linked genes for protein and leaf rust resistance (46, 67).

Inheritance data from a cross of a high protein Atlas 66-derived Nebraska experimental line with a high protein Aniversario-derived line provided evidence that the parent lines possessed major protein genes in common (Lay thesis).

Data from studies involving corsses of Nap Hal with other wheats revealed mostly additive genetic effects for protein (Kuhr, Diehl). Evidence that Nap Hal and April Bearded have genes in common for high protein was obtained (Diehl thesis). In crosses of Nap Hal with the Mexican spring semi-dwarf varieties C.B. No. 113 and Pitic 62, and the tall spring wheats Selkirk and Justin, correlations between protein and plant height were small and mostly non-significant. Heritability estimates for protein were as high as 88% and for adjusted lysine as high as 71% (Kuhr M.S. thesis).

Relationship between Protein and Lysine

A curvilinear negative relationship exists in wheat between protein and lysine per unit protein (Figure 11). Increases in protein up to 15% are associated with strong depression of lysine per unit protein. Above 15% protein there is little or no further depression of lysine (76, 79).

Lysine per unit grain weight is strongly positively correlated with protein (Figure 12). Increased protein content results in significant increases in lysine and all other essential amino acids per unit weight of grain.

Because of the strong effect of protein level on lysine percent of protein, comparisons of lysine values among wheats that differ in protein content have little validity. The Nebraska project developed a mathematical model to adjust lysine values to a common protein level to enable valid lysine comparisons among wheats differing in protein (76, 79).

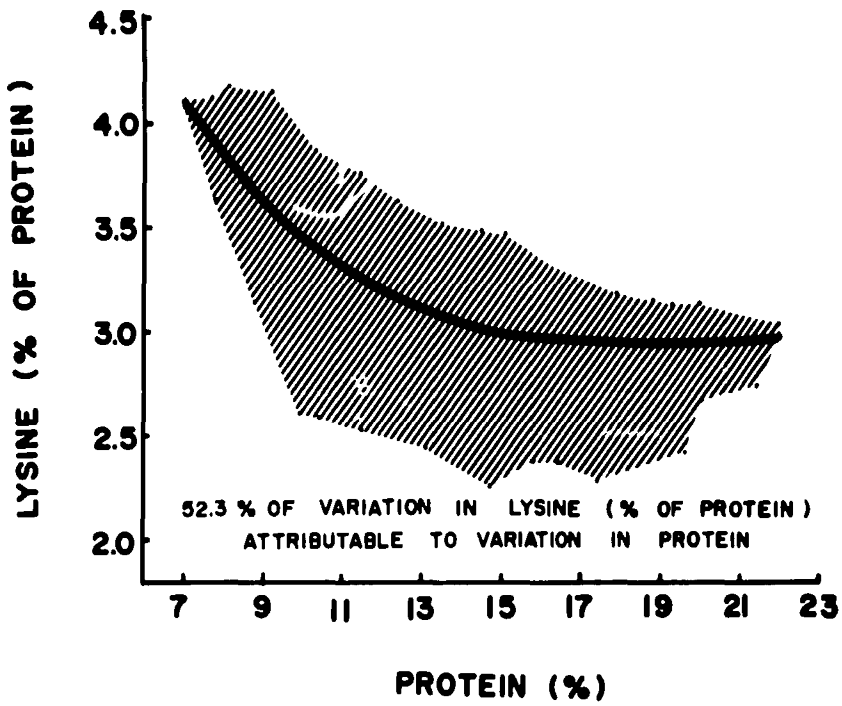


Figure 11. A curvilinear negative relationship exists between grain protein and lysine (% of protein) in wheat that largely disappears above 15% protein (52% of lysine variation is attributable to variation in protein).

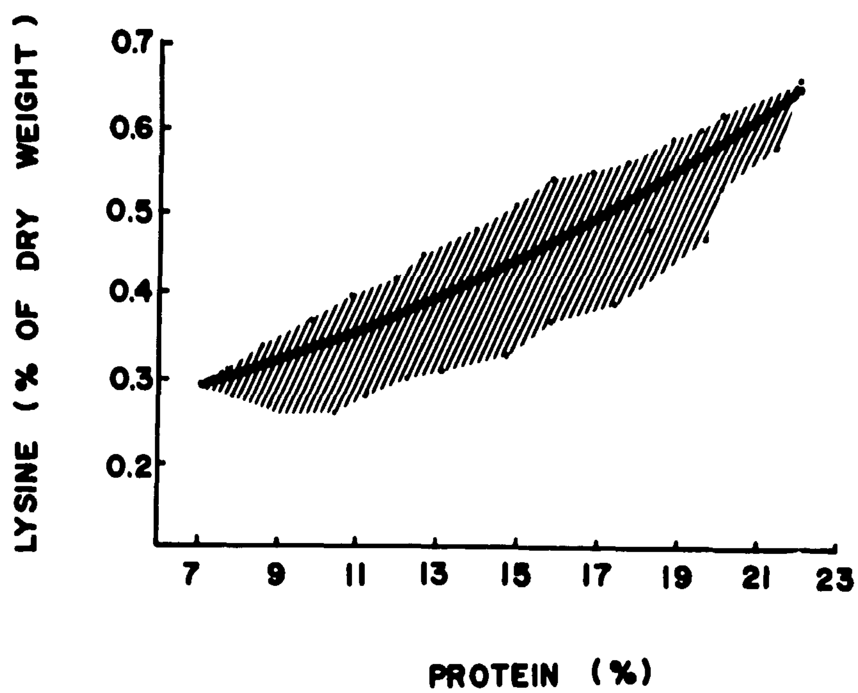


Figure 12. A strong positive correlation exists between grain protein and lysine (% of dry grain weight) in wheat.

Relationship between Yield and Protein

Yield of grain unquestionably influences the protein content of the grain. In many production situations high yields can be expected to result in depressed protein content of the grain. This has led some wheat breeders to believe incorrectly that elevated grain protein can be achieved only at the expense of yield. Accumulated data from this project provide strong evidence that true genetic differences in protein exist in wheat and that elevation of protein by breeding can be accomplished without reduction of grain yield.

The strong influence of yield on protein in many environments necessitates simultaneous monitoring of both traits for breeding progress. The validity of genetic studies of protein content independently of grain production can be challenged and, indeed, high protein lines so identified usually are also non-productive.

In a 3-year study at low fertility sites in Nebraska, a high protein winter wheat (C.I.14016) was compared with the Lancer variety under 7 levels of applied nitrogen (17). The two wheats responded similarly both in yield and protein to applied nitrogen (Table 15). C.I.14016 was equal to Lancer in yield and maintained approximately 2 percentage points protein advantage over Lancer at all levels of N-application. These results suggest that C.I.14016, at all levels of soil nitrogen availability, took up from the soil and/or translocated more nitrogen to its grain than did Lancer.

Table 15. Average yield and protein responses of C.I.14016 and Lancer wheat varieties to nitrogen fertilizer at several Nebraska test sites in 1969 and 1970.

Nitrogen applied (kg/ha)	Grain yield (q/ha)		Protein content (%)	
	Lancer	CI14016	Lancer	CI14016
0	25.9	25.8	10.8	12.5
22.5	29.9	27.4	11.2	13.3
45	31.4	29.5	11.8	14.0
67.5	31.1	30.6	12.6	14.9
90	31.1	30.3	13.2	15.4
112.5	30.7	30.5	13.6	15.8
135	30.2	31.1	14.0	16.3
$LSD_{.05}$	1.1	1.1	0.3	0.3

Further evidence that high yield and high grain protein content are compatible was obtained in Ph.D. theses research by K. Wilhelmi and M. da Silva. Wilhelmi determined that both the yield and the grain protein content of the high-protein varieties Lancota and Nebraska

Restorer 3547 were significantly higher than Lancer at Lincoln, Nebraska. da Silva established that NE7060 (Favorit/5/Cirpiz//Jang Kwang/4/At 66/Comanche/3/Velvet) and Lancota produced significantly the highest grain yield and grain protein content among 5 varieties studied at Lincoln.

Correlations of yield with protein and 1000-kernel weight with protein were computed at 62 IWWPN sites from which data were available in 1976 and 1977 (Table 16). In 1976 no correlation of yield with protein could be demonstrated at 17 of 47 sites and in 1977 at 16 of 56 sites. At only 11 sites could twenty-five percent or more of protein differences be attributed to yield in 1976 and at only 9 sites in 1977.

No relationship of 1000-kernel weight with protein existed at 21 of 33 sites in 1976 and at 29 of 35 sites in 1977. Where a relationship could be demonstrated, high 1000-kernel weight was more often associated with high protein than low 1000-kernel weight.

These data indicate that differences in yield of grain seldom account for the major portion of the differences in grain protein content and there is essentially no relationship of kernel weight with protein content.

Table 16. Relationship of grain yield and 1000-kernel weight to grain protein among varieties tested in the IWWPN in 1976 and 1977.

Nursery site	Correlation: Yield vs. protein				Correlation: 1000-k. wt. vs. protein			
	1976		1977		1976		1977	
	r	r^2	r	r^2	r	r^2	r	r^2
Herat, Afghanistan	.23**	.05	-.38**	.14	.52**	.27	ns	
Kabul, Afghanistan	ns[1]		ns		ns		ns	
Algiers, Algeria	ns		--		--		--	--
Balcarce, Argentina	--[2]	--	--		-.45**	.20	ns	
Bordenave, Argentina	ns		ns		.47**	.22	ns	
Vienna, Austria	ns		ns		ns		ns	
Tolbukhin, Bulgaria	-.57**	.32	-.21*	.04	ns		ns	
Lethbridge, Canada	--	--	-.47**	.22	--	--	ns	
Prince Edward Island, Canada	--	--	-.36**	.13	--	--	ns	
Chillan, Chile	--	--	-.22*	.05	--	--	ns	
Temuco, Chile	-.63**	.40	--		.68**	.46	--	--
Male Ripnany, Czechoslovakia	-.53**	.28	--		ns		--	--
Sedlac, Czechoslovakia	--	--	-.66**	.44	--	--	.25**	.06
Bohnshausen, GDR	-.26**	.07	-.40**	.16	ns		.22*	.05
Cambridge, England	-.45**	.20	--		-.26**	.07	--	--
Jokioinen, Finland	ns		-.27*	.07	--	--	--	--
Orgerus, France	-.30**	.09	ns		--	--	--	--
Martonvasar, Hungary	ns		ns		.28**	.08	.44**	.19
Szeged, Hungary	ns		ns		ns		ns	
Hamadan, Iran	ns		-.45**	.20	--	--	--	--
Karaj, Iran	ns		-.28**	.08	--	--	--	--
Sulaimaniya, Iraq	-.34**	.12	-.58**	.34	ns		ns	
Milano, Italy	-.45**	.20	-.36**	.13	ns		ns	
Rieti, Italy	ns		ns		.21*	.04	ns	
Morioka, Japan	-.48**	.23	-.46**	.21	--	--	ns	
Amman, Jordan	ns		-.28**	.08	ns		ns	
Suweon, Korea	-.70**	.49	-.74**	.55	-.22*	.05	ns	
Beirut, Lebanon	ns		--		--	--	--	--
Toluca, Mexico	--	--	-.45**	.20	--	--	--	--
Kathmandu, Nepal	--	--	-.48**	.23	--	--	ns	
Wageningen, Netherlands	-.61**	.37	-.67**	.45	ns		ns	
Vollebekk, Norway	-.50**	.25	ns		ns		ns	
Przeclaw, Poland	--	--	-.29**	.08	--	--	.25**	.06
Radzikow, Poland	ns		-.28**	.08	.20*	.04	ns	
Fundulea, Romania	ns		ns		--	--	--	--
Bethlehem, Rep. South Africa (irrig.)	ns		ns		--	--	--	--
Bethlehem, Rep. South Africa (rainfed)	-.19*	.04	ns		--	--	--	--
Svalof, Sweden	-.57**	.32	-.33**	.11	ns		ns	
Zurich, Switzerland	-.32**	.10	ns		ns		ns	
Aleppo, Syria	--	--	ns		--	--	--	--
Ankara, Turkey	ns		-.37**	.14	ns		--	--
Erzurum, Turkey	-.68**	.46	ns		-.35**	.12	.21*	.04
Eskisehir, Turkey	-.38**	.14	ns		ns		-.51**	.26
Davis, California-USA	--	--	-.20*	.04	--	--	--	--
Akron, Colorado-USA	--	--	-.69**	.48	--	--	--	--
Ft. Collins, Colorado-USA	-.43**	.18	-.58**	.34	--	--	--	--
Brookston, Indiana-USA	--	--	-.45**	.20	--	--	ns	
Hutchinson, Kansas-USA	--	--	-.31**	.10	--	--	--	--
Billings, Montana-USA	ns		-.33**	.11	--	--	--	--
Lincoln, Nebraska-USA	-.72**	.52	-.54**	.29	-.56**	.31	ns	
Ithaca, New York-USA	-.50**	.25	-.31**	.10	--	--	--	--
Rowen County, North Carolina-USA	-.56**	.31	-.36**	.13	--	--	--	--
Stillwater, Oklahoma-USA	-.50**	.25	-.50**	.25	-.46**	.21	--	--
Corvallis, Oregon-USA	--	--	-.47**	.22	--	--	--	--
Pullman, Washington-USA	-.23**	.05	-.47**	.22	--	--	--	--
Krasnodar, USSR	-.47**	.22	-.26**	.07	ns		ns	
Mironovski, USSR	--	--	-.32**	.10	--	--	--	--
Odessa, USSR	-.68**	.46	ns		ns		ns	
Monsheim, West Germany	-.50**	.25	-.65**	.41	ns		ns	
Weihenstephan, West Germany	-.65**	.42	-.67**	.45	ns		ns	
Novi Sad, Yugoslavia	-.42**	.18	-.41**	.17	ns		--	--
Zagreb, Yugoslavia	-.26**	.07	-.26**	.07	ns		ns	

[1] ns = Statistically non-significant.
[2] -- = Data for correlation not available.

OBJECTIVE 4

Chemical and Biological Evaluations

The Nebraska project from the outset has relied on laboratory chemical analyses of protein and amino acids, particularly lysine, as reliable and acceptable indicators of nutritional value of wheat. The large numbers of wheats in the World Collection and from the project protein breeding and genetic investigations required analyses that could be done quickly and efficiently. Small animal bioassays could not accommodate such large numbers.

Although it was well established that, in wheat protein, lysine is the critical essential amino acid and is present in less than one-half the amount required for nutritional balance, little was known about the effect of protein level in wheat on the amino acid composition of the protein. Results of amino acid analyses of 114 low protein and 50 high protein wheats from the World Collection established that lysine was substantially higher in the low protein than in the high protein group. Consistent with the results of our analyses of the entire World Collection, a moderately large negative correlation between protein and lysine (-0.60) existed among wheats in the low protein group but a non-significant correlation in the high protein group (R-7). Methanine, threonine and leucine also were negatively correlated with level of protein among the low protein wheats but only threonine was negatively correlated with protein in the high protein group. In both groups lysine was positively correlated with threonine, leucine, and tyrosine but negatively correlated with valine.

Despite the negative correlations of lysine, methionine, threonine, and leucine with protein level, comparisons of high lysine with high protein wheats demonstrated that more of every essential amino acid per weight of grain was provided by the high protein wheats than by the high lysine but lower protein wheats (6). Further, our comparisons by chemical analyses indicated that high protein wheat lines that averaged 17% protein would provide more lysine, isoleucine, methionine, and threonine per unit weight of grain than would opaque-2 maize containing 10% protein (6).

Small Animal Bioassays -- Extensive mouse-feeding trials were conducted in 1971 and 1972 to assess the nutritional value of high protein and high lysine wheats from our program. In mice fed equal amounts of wheat differing in protein and/or lysine weight gains and feed efficiency ratios (FER) were generally better from high protein than low protein wheats (23). Unexplained inter-animal variations reduced the reliability of the trials. When the mouse diets were fed at equal levels of protein, wheats with the highest levels of lysine per unit protein usually gave the highest protein efficiency ratios (PER). Correlations between the two usually were low but in some trials highly significant statistically (0.21**). When the product of PER and protein content of the wheats fed was calculated to reflect the combined value of protein quantity and quality, those lines with the highest protein usually provided the highest product values (R-13). Nap Hal-derived lines in which high protein was combined with relatively high lysine provided the best product values among the wheats tested.

Rat bioassays of high protein and high lysine wheats, mostly derived from crosses involving Atlas 66, Nap Hal or C.I.13449 were contracted with the Warf Institute as part of a Ph.D. thesis research by S. L. Kuhr. The wheat protein was evaluated by the slope-ratio method, relative protein value (RPV) and relative nutritive value (RNV). Feed consumption and animal weight gain were negatively correlated with grain protein content whereas lysine/protein was positively correlated with diet consumption and weight gain. The RPV and RNV values were highly correlated and both were correlated with lysine percentage of protein. Relative utilizeable protein which reflects both quantity and quality of protein, was positively correlated with grain protein content. Grain protein values among wheats evaluated both in 1976 and 1977 were positively correlated as were lysine per unit protein values. Bioassay nutritive values (RPV and RNV) did not show close agreement between the two years suggesting existence of dietary factors other than nutritive value of the test protein or differences associated with the test animals.

Human Bioassays -- In comparisons of whole wheat and white flour from Nap Hal, Atlas 66, Centurk and Bezostaya 1 by adult human bioassays Nap Hal exhibited the poorest digestibility while Atlas 66 and Centurk provided the best N-balance at equal intakes of nitrogen whereas Atlas 66 and Nap Hal provided the best N-balance on an equal product intake basis (R-13). Nitrogen balances were comparable for whole wheat and white flour of Nap Hal both at equal intakes of nitrogen and flour whereas for Atlas 66 they were comparable only at equal intakes of nitrogen. Centurk and Bezostaya 1 white flour produced poorer retentions of N than whole wheat flour, both at equal intakes of nitrogen and of flour.

When whole wheat and white flours from the same 4 varieties were fed to adolescent boys, the N-balances were in the negative range (R-13). Atlas 66 and Nap Hal provided the best N-balance among the varieties both in whole wheat and white flour form. N-balances provided both the whole wheat and white flours were not significantly different for any of the wheats except Centurk.

Further evaluation of whole wheat and white flour from Nap Hal and Atlas 66 and a commercial variety was done at the British-American Hospital in Lima, Peru where convalescing malnourished children were the subjects (R-13). Mean apparent retention of the white flour of both Atlas 66 and Nap Hal was less than from its whole wheat flour, indicating that whole wheat protein quality was superior to that of the endosperm in both varieties. Nap Hal was somewhat inferior to Atlas 66 in both flour forms. It was the conclusion of Dr. Graham, Johns Hopkins University, who was in charge of the study that Atlas 66 offers a significant advantage in terms of human nutrition if consumed on a whole wheat basis.

Comparison of In Vitro and In Vivo Assays -- Human subject assays are unacceptable for routine evaluation of food quality because of time and cost. Sample size requirements are an added constraint. Rapid protein evaluation methods developed recently employ amino acid content and biological assays to measure protein digestibility and small organism growth. The tests generally require less than five days.

The Food Protein Research Group at the University of Nebraska developed two assay methods which require less than three days to complete. (Satterlee, L. D., N. F. Marshall and J. M. Tennyson. 1979. Measuring protein quality. J. Am. Oil Chemists Soc. 56:103-109.) One method, a C-PER assay, uses In vitro protein digestibility data and essential amino acid (EAA) composition to predict food protein quality in terms of PER.

Sixty wheats previously assayed for relative protein value (RPV) by S. L. Kuhr (Ph.D. thesis) were used to evaluate the C-PER method. In vitro protein digestibility was determined using a multi-enzyme technique of Hsu, H. W., D. L. Vavak, L. D. Satterlee and G. A. Miller. 1977. J. Food Sci. 42:1269. Amino acid compositions were determined following protein hydrolysis by three methods prior to analysis on a Beckman 120C amino acid analyzer: 1) 6N HCl under vacuum for 24 hrs. at 110°C; 2) Tryptophan from $Ba(OH)_2$ hydrolysis (E. L. Miller. 1967. J. Sci. Food Agr. 18:381) and ion-exchange chromatography determination of the hydrolyzate (R. Knox, G. Kohler, R. Palter and H. Walker. 1970. Anal. Biochem. 36:136-143); and 3) Analysis of sulfur-containing amino acids by performic acid treatment followed by hydrolysis with 6N HCl for 24 hrs. at 110°C. (S. Moore. 1963. J. Biol. Chem. 238:235-237.)

Lysine, methionine + cystine, threonine, isoleucine, leucine, valine, phenylalanine + tyrosine, and tryptophan were the essential amino acids used in our computation. Calculations were done according to the 1979 Satterlee et. al. reference using the C-PER Model developed from known samples with corrected rat PERs ranging from 0.67 to 3.22. The C-PER model was programmed for computer use. Correlations of pertinent data appear in Table 17.

Table 17. Correlations of C-PER with RPV (relative protein value, RUP (relative utilizeable protein), S. L. Kuhr's unofficial PER (U-PER at 8.4% protein), and lysine % of recommended FAO value. (N=60)

	r-value			
	RPV	RUP	U-PER	% FAO lysine
C-PER	0.57	0.03	0.74	0.96

The % FAO lysine parameter is equivalent to the chemical score for lysine. Based on the high correlation of % FAO lysine with C-PER, the chemical score for lysine utilized in the Nebraska wheat protein project is an accurate and acceptable alternative to the more time-consuming C-PER procedure for evaluation of wheat protein quality.

Processing Quality -- Early plant breeding efforts in the project were concerned with combining high protein-high lysine lines with improved agronomic types. Little attention was given to processing quality at this early stage. An important source of high protein and lysine, the variety Nap Hal, was known to possess poor milling and baking quality.

Flours from a number of advanced lines, which had superior agronomic characteristics, were evaluated for their milling and dough mixing (mixogram) properties in 1975. (Comprehensive report in Project Report April 1, 1975-March 31, 1976.) The samples exhibited a wide range in quality potential. One cross, Favorit/5/Cirpiz/4/Jang Kwang/2/At 66/Cmn/3/Velvet (NE7060) was of particular interest because it combined good milling and baking potential along with outstanding agronomic traits.

Milling and mixogram data were obtained on 200 productive high protein-high lysine lines grown at Yuma, Arizona under irrigation in 1977. One hundred samples each of winter and spring growth habit types were selected based on their yield and protein superiority.

Sixteen winter lines had satisfactory mixing characteristics when compared to the four controls Bezostaya, C.I.13449, Centurk and Lancota. 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 13).

Nine of the sixteen winter types selected for their mixing characteristics had hard milling properties as judged by bran clean-up and flour yield.

Fifteen spring lines had satisfactory mixing properties when compared to the Nap Hal, Atlas 66, INIA 66, and C.I.13449 controls (Figure 14). 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. 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.

Promising agronomic material from advanced lines harvested in 1979 was tested in order to identify future IWWPN candidates with known processing quality.

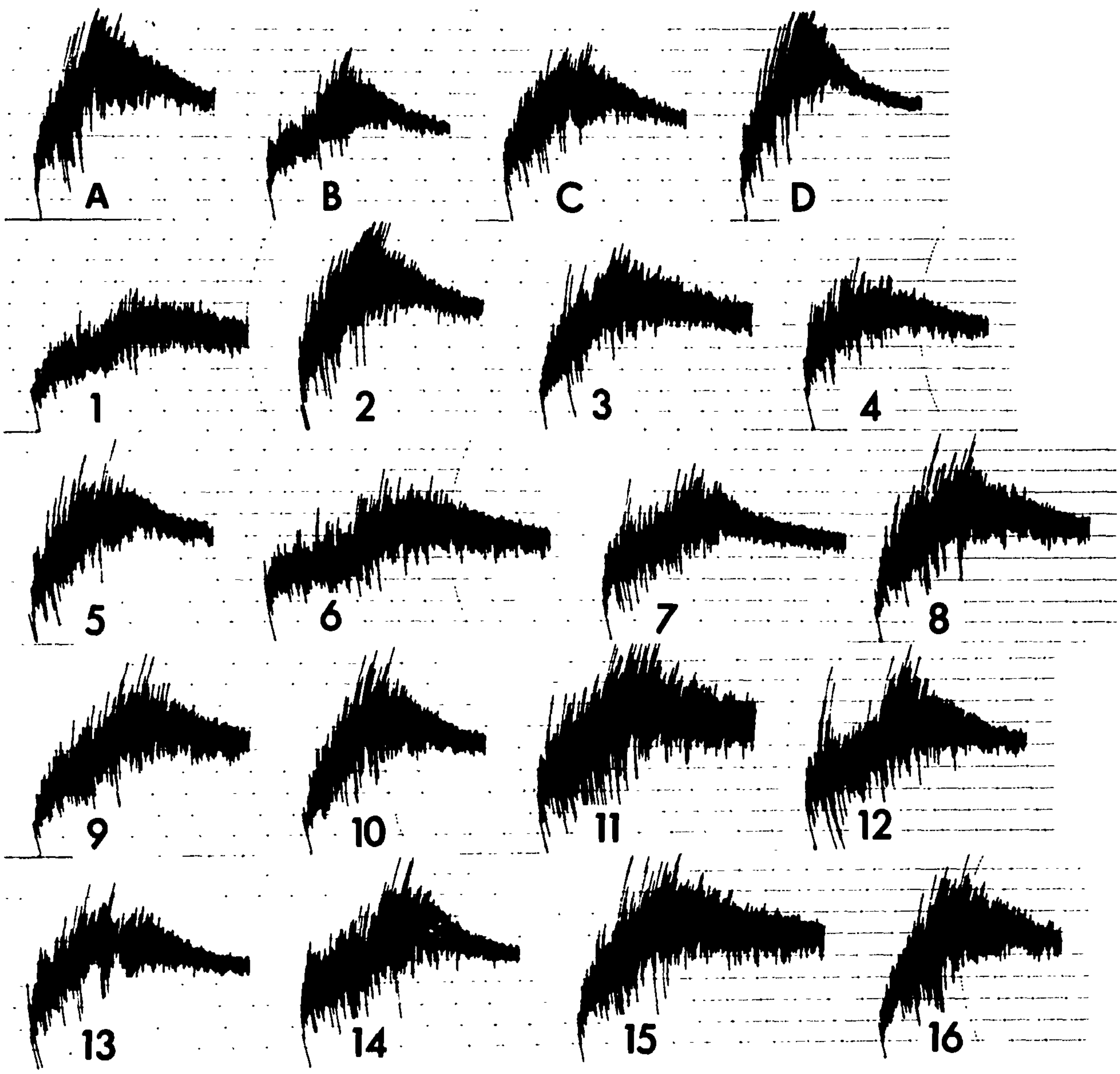


Figure 13. Mixing curves for High Protein-High Lysine Observation Nursery, winter selections, Yuma, Arizona, 1977. A, Bezostaya; B, C.I.13449; C, Centurk; D, Lancota; 1, 77Y1010; 2, 77Y1013; 3, 77Y1029; 4, 77Y1037; 5, 77Y1049; 6, 77Y1050; 7, 77Y1055; 8, 77Y1084; 9, 77Y1086; 10, 77Y1087; 11, 77Y1091; 12, 77Y1112; 13, 77Y1127; 14, 77Y1140; 15, 77Y1150; 16, 77Y1157.

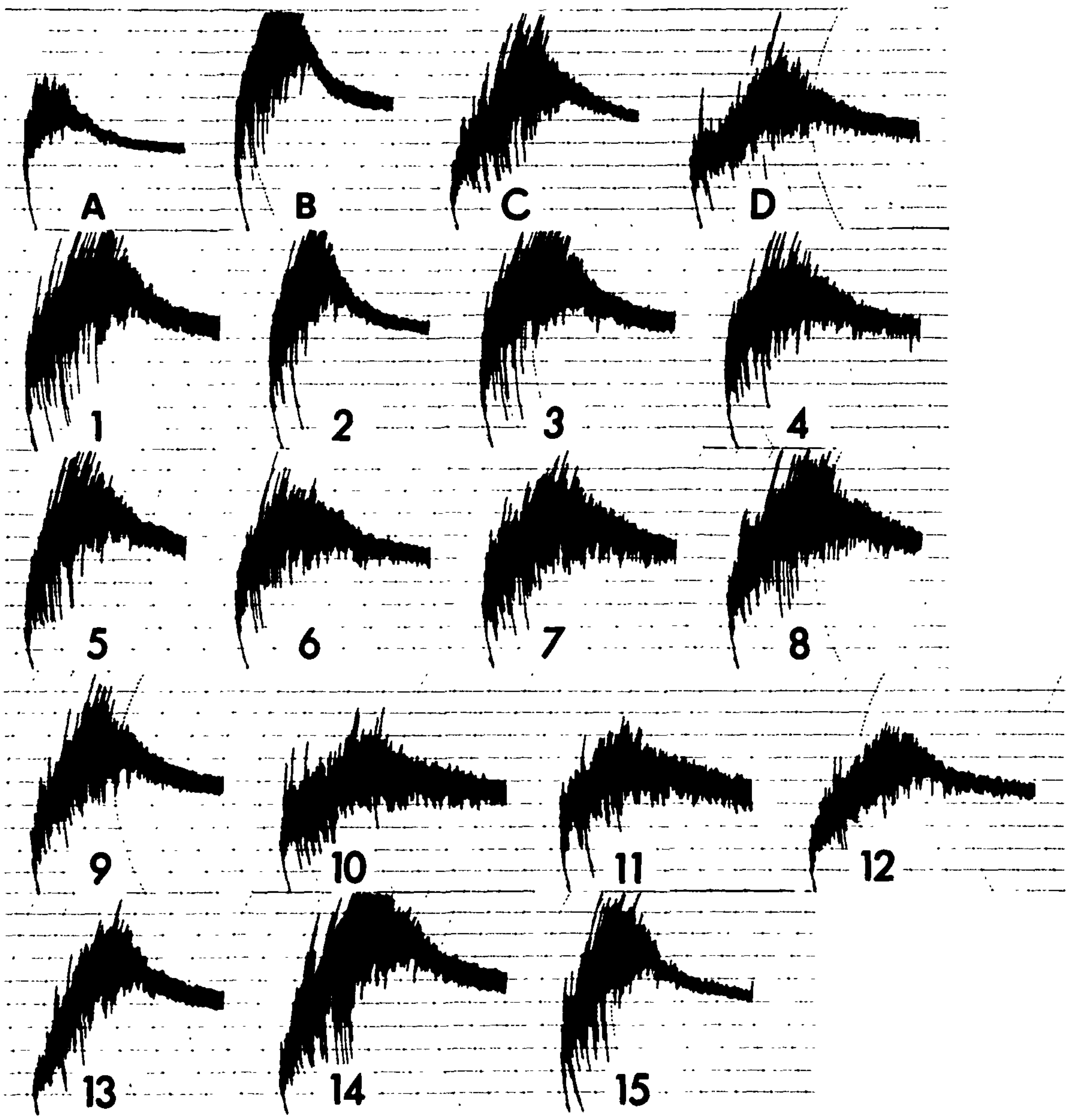


Figure 14. Mixing curves for High Protein-High Lysine Observation Nursery, spring selections, Yuma, Arizona, 1977. A, Nap Hal; B, Atlas 66; C, INIA 66; D, C.I.13449; 1, 77Y1269; 2, 77Y1270; 3, 77Y1271; 4, 77Y1274; 5, 77Y1275; 6, 77Y1277; 7, 77Y1310; 8, 77Y1313; 9, 77Y1320; 10, 77Y1326; 11, 77Y1329; 12, 77Y1360; 13, 77Y1361; 14, 77Y1378; 15, 77Y1380.

Four of the twelve experimental lines had acceptable dough mixing properties and mixing times were intermediate to the controls (Figure 15).

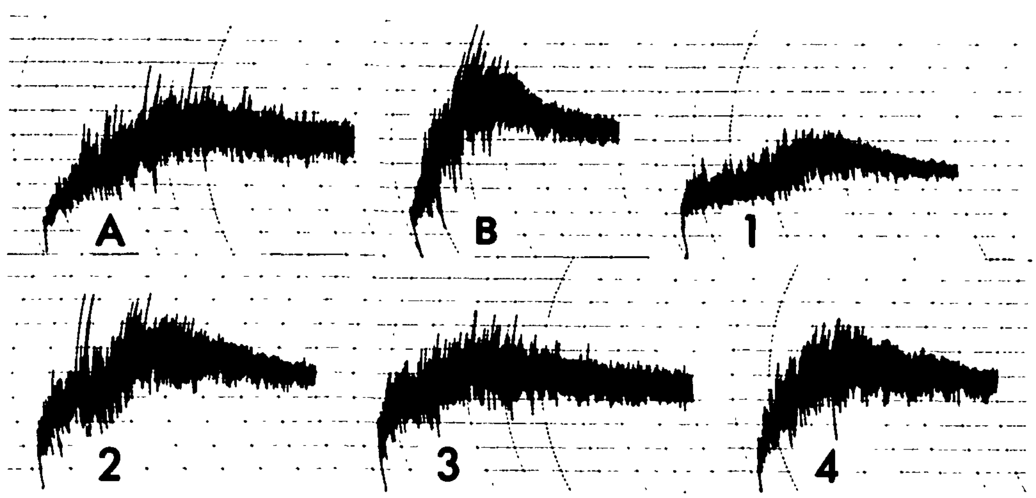


Figure 15. Mixing curves for IWWPN candidate varieties, winter selections, Yuma, Arizona, 1979. A, Centurk 78; B, Lancota; 1, 90576; 2, 90537; 3, 95097; 4, 9044.

When selecting parental germplasm with improved protein and lysine, plant breeders should also combine as many of the quality characteristics necessary for the wheat products of their region. This could save development time by reducing the number of backcrosses to their local quality types.

Laboratory Techniques -- Investigations by plant breeders to improve the nutritional value of cereals have been delayed because laboratory methods and equipment were inadequate. Several significant improvements and modifications of laboratory equipment were made in the Nebraska project to enable large numbers of samples to be analyzed quickly and for a reasonable cost.

Sample preparation was time consuming until the development of the Udy Cyclone Mill.[1/] Fins of a propellor force grain against an abrasive surface for rapid grinding. A 1 mm screen holds the sample in the grinding chamber until particles have been reduced to size. An alternative 0.5 mm screen produces more residue in the grinding chamber and requires more cleaning between samples.

Laboratories engaged in the analyses of cereal products often spend large amounts of time for the determination of moisture. If analyses need not be determined immediately, a moisture equilibration cabinet can be used to bring samples to a uniform moisture content.

1/ Mention of firm names or trade products does not imply that they are recommended by the U. S. Department of Agriculture and the Agency for International Development over other firms or similar products not mentioned.

This arrangement is particularly useful in laboratories which analyze large blocks of material over several weeks. We employed the system for wheat nursery materials and for the screening of the USDA World Wheat Collection.

In addition to the time saved in running a large number of moisture determinations, it is possible to weigh to a definite moisture basis and eliminate the need to convert data to a moisture level following the analytical determination. P. Mattern and J. Bishop. A cabinet with controlled humidity to bring cereal samples to constant moisture. Cereal Sci. Today 18:8-10 (1973). (Figure 16.)

Figure 16. Moisture equilibrating cabinets holding 5000 samples each.

Micro Kjeldahl equipment has been improved during the past 15 years. Forty-unit digestors for micro-samples produced by Tecator and operated with a fume scrubbing device located in a chemical band, provide efficient digestion. Coupled with Tecator's automatic steam distillation unit large numbers of samples can be processed. Some research groups find the Technicon auto analyzer for color development a useful alternative to distillation.

We consider ion exchange chromatography the most reliable method for determination of lysine and other amino acids. Automated amino acid analyzers are expensive and require highly trained competent technicians for productive operation. Laboratories with minimal financial support and technical personnel should consider other available methods for lysine determinations.

Screening of the World Wheat Collection for lysine differences in our laboratory was done with a Beckman Automatic Amino Acid Analyzer modified with four short (5 cm) columns packed with PA 35 resin. Samples were acid hydrolyzed prior to analysis. Our procedure was programmed so that only the lysine peak was recorded and integrated with a Beckman Integrator Model 125. With this procedure a competent operator analyzed 50 prepared samples per day. Automatic sample applicators are now available which reduce the manual labor considerably (Figure 17).

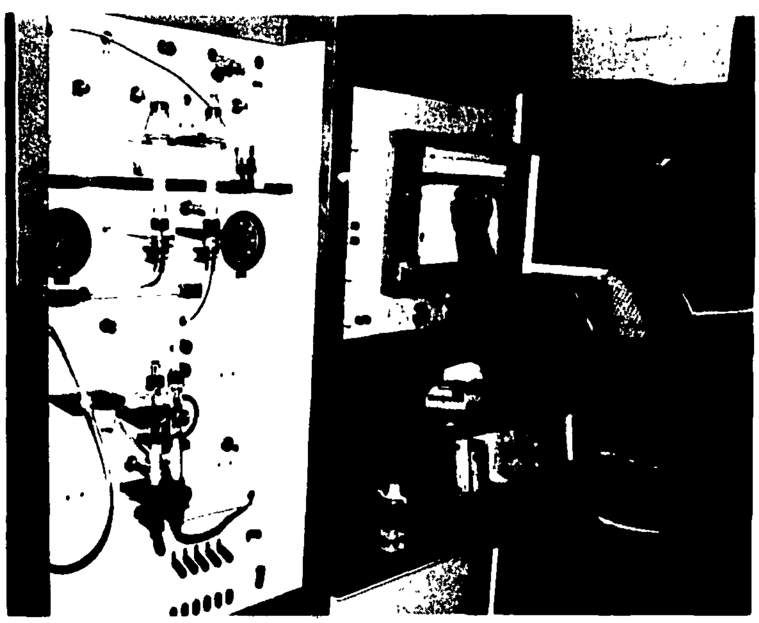


Figure 17. Amino acid analyzer modified with four short columns and an integrator to analyze 50 prepared samples per day.

Mossberg (Sweden) demonstrated that dye-binding capacity (DBC) of barley, wheat, oats, rye, triticale, and maize was more highly correlated with basic amino acid content (r = 0.940) than with nitrogen and crude protein content (r = 0.767). Lysine was correlated with DBC (r = 0.819). Munck (Sweden) incorporated into the DBC procedure the weighing of samples to a constant amount of protein.

We utilized a modification of the Mossberg-Munck procedure. Crude protein content of a wheat sample was determined by Kjeldahl. A ground sample containing 65 mg of protein was shaken for one hour with 25 ml solution containing 1.3 mg/ml of dye (Udy Analyzer Company commercial dye) in a 50-ml polycarbonate centrifuge tube. The mixture was centrifuged in accordance with the Udy Method procedure. "Apparent" lysine was determined from a standard curve prepared from known lysine data determined by ion exchange chromatography. Our DBC data correlated well with standard lysine values (r = 0.78).

More complete information on methods and equipment was published in previous Progress Reports for this project, December 1972, March 31, 1975, March 31, 1976 and March 31, 1977. Additional information may be found in Proceedings of the four International Conferences which were sponsored by this project.

OBJECTIVE 5

Nitrogen Metabolism and Photosynthesis

Elevated grain protein content in wheat results both from increased uptake of nitrogen by the plant as well as more complete translocation of nitrogen from the foliage to the grain during grain maturation. Initial evidence of the latter was obtained from a 3-year comparison of high and normal protein varieties in Nebraska (17). This was subsequently substantiated in a Ph. D. thesis study by K. D. Wilhelmi who demonstrated that less nitrogen remained in the straw of varieties Lancota and Nebraska Restorer at harvest time than in the ordinary-protein variety Lancer in a 2-year study at Lincoln. Both of the high-protein varieties were higher yielding than Lancer. Nebr. Restorer 3547 and Lancota translocated 19.8 and 23.8% more of their foliage nitrogen to their grain than Lancer.

In the first year of the Wilhelmi study, differential soil nitrogen uptake among the three varieties could not be demonstrated but, in the second year, both Lancota and Nebr. Restorer 3547 absorbed significantly more soil N than Lancer.

Removal of the flag leaf and 4th leaf of 5 varieties at heading time by M. da Silva (Ph.D. thesis) significantly reduced grain yield and protein content of the varieties, indicating the importance of these leaves in protein and carbohydrate accumulation in the grain during the maturation period.

Seed size was determined not to have significant influence on the protein content of the seed. In a study in which seed of a variety was first separated into size classes, then each class further divided into sub-classes according to degree of shrivelling or plumpness, protein differences between size classes of equal seed plumpness were not significant, whereas the plumpness subclasses within each size class were different in protein content (6). Seed size reflected by 1000-kernel weight could not be demonstrated to influence protein content of varieties in the IWWPN during a 2-year period (Table 16).

Atlas 66 genes for high protein mainly influence the protein content of the starchy endosperm, the portion of the wheat kernel that is milled into white flour. Nap Hal genes affect the starchy endosperm as well as the bran fraction of the kernel -- hence the full effect of its protein genes would not be expected to be retained in white flour (29). Lancota, the high protein winter variety derived from an Atlas 66 cross, produces white flour that exhibits the same magnitude of protein superiority over other varieties as does its whole grain demonstrating that the high protein effect resides in the starchy endosperm. A correlation of endosperm and whole grain protein as high as 0.98 indicates that selection for high protein, on the basis of whole grain, will reliably reflect endosperm protein level.

Chemical fractionation of endosperm proteins was done by R. Ulmer as a part of his Ph.D. research. High protein in Atlas 66 was found to be associated with an increase of the alcohol-soluble fraction and a decrease in the alkali-soluble fraction. Increases in endosperm lysine associated with low protein are explained mainly by the decrease in the alcohol fraction and the accompanying increase in the salt fraction.

Associative Nitrogen Fixation -- Associative nitrogen fixation which is defined as nitrogen fixation by free-living microorganisms in the root-rhizosphere environment was studied with winter wheat, sorghum and perennial grasses. The general approach was to survey multiple locations and plant genotypes for associative nitrogen fixation using acetylene reduction by root segments, roots, soil-root cores or intact plants as an indicator. Nitrogen-fixing bacteria were isolated and identified from those materials exhibiting nitrogenase activity. Selected plant genotypes and nitrogen-fixing isolates were used for field and growth chamber experiments. Winter wheat samples from approximately 150 sites and 3000 samples of either root segments or soil-plant cores collected over a period of 3 years throughout Nebraska had very low or no nitrogenase activity. Values ranged from 0 to 3.1 nmol C_2H_4 produced per hr per g dry weight.

A commercial field of winter wheat variety Scout 66 did exhibit some activity with root segments (290 nmol of C_2H_4 produced per h per g dr wt of root segment) during one season. The activity appeared to be localized with 85% of the activity being found in 2-cm segments below the crown of the root. The roots were extremely fibrous and the root systems below the crown were unusually large in diameter. The predominant nitrogen-fixing bacteria isolated from root segments of these wheat plants were identified primarily as members of Enterobacteriaceae including *Klebsiella pneumoniae*, *Enterobacter cloaceae* and *Erwinia herbicola*. Roots from the same wheat field taken during 3 subsequent years, from other fields in the same area and of the same wheat variety, did not exhibit nitrogenase activity. The nitrogen-fixing isolates and soil from the field which had activity associated with the roots were used as wheat seed inoculants in plant growth chamber and field studies. In the plant growth chamber studies, varieties Sadova 1 and Mironovskaya 808 consistently exhibited nitrogen fixation associated with their roots. None of the field studies involving wheat seed inoculation gave any positive nitrogenase activity.

Sorghum and the perennial grass, *Poa pratensis*, were selected to supplement the winter wheat studies because of their differences in photosynthetic properties and cultural practices. Of 400 sorghum lines and crosses, grain sorghums (e.g. CK-60A, Wheatland A, B517 and NP-16) generally exhibited higher nitrogenase activity in roots than forage sorghums or winter wheats with values ranging from 0 to 1100 nmol of C_2H_4 formed per h per core. Significant differences were observed among 12 lines of sorghum tested for acetylene reduction with roots from lines R-8193 and CK 60B exhibiting the highest activity.

Two 3^2 x 5 factorial experiments were designed to test the effect of 1) three levels of nitrogen or three levels of phosphorus; 2) three lines of lines of sorghum (CK 60A, CK 60B and B 517; and 3) five bacterial inoculants (live and heat-killed nitrogen-fixing isolates) on acetylene reduction levels, forage yields, forage nitrogen levels, grain fields and grain nitrogen levels. Statistical analysis of the acetylene reduction assays did show significant differences in nitrogenase activity for all factors and for all interactions except the line factor in the phosphorus experiment. Supplemental nitrogen gave a decrease in nitrogenase activity for all three lines. No significant difference was obtained by the inoculant factor in the analysis of forage yield, forage nitrogen, grain yield and grain nitrogen. The fertilizer and inoculations interaction for forage yield did show an increase yield response to the bacterial inoculants.

Turfs of 'Park', 'Nugget' and 'South Dakota Certified' cultivars of Kentucky bluegrass were inoculated with nitrogen-fixing bacterial isolates and evaluated for nitrogen fixation using the acetylene reduction assay and the accumulation of nitrogen as indicators. 'Park' turfs inoculated with live Klebsiella pneumoniae (W-6), an isolate from wheat roots, gave significantly higher nitrogenase activity and accumulation of nitrogen in the aerial portions of the plants than 'Park' turfs inoculated with heat-killed K. pneumoniae (W-6). Significant differences were not observed among any of the combinations of turfs and inoculants.

Nitrogen Loss from Wheat Plants -- Field experiments measuring nitrogen uptake in winter wheat have shown large losses of nitrogen from the plant tissue. These losses were as large as 40 kg/ha and occurred after the flowering stage. It was hypothesized that volatilization of the plant nitrogen was occurring. A "gas tight" growth chamber was constructed and ammonia (NH_3) and nitrous oxides (NO, NO_2) were investigated as potential gaseous nitrogen loss products. Only ammonia was found to be involved in significant quantities. The rate of ammonia evolution increased greatly when plants reached the flowering stage, which coincided with the nitrogen loss pattern observed in the field. At no time, however, were ammonia losses large enough to account for the sizeable losses of nitrogen observed in the field. The findings in these experiments are significant in that they do indicate wheat plants lose gaseous nitrogen as ammonia and do so after flowering occurs. This may partially explain what people have considered as inefficient use of nitrogen fertilizers by plants like wheat. For example, if the total quantity of nitrogen in the wheat plant at maturity is compared to the soil and fertilizer nitrogen used to produce it, a falsely low percentage of the available nitrogen will appear to have been absorbed by the plant. Our data suggest that plants do absorb the nitrogen and then lose it from flowering to maturity as a gaseous product.

Photosynthetic Efficiency -- An investigation of photosynthetic efficiency in wheat was initiated late in the project. Measurements of light interception and field photosynthesis were made. In a comparison of selected genotypes plant height up to one meter was positively correlated with light interception (r=.64). Reduced light interception of short varieties could be partially compensated by the use of narrow row spacing. Reduction of distance between rows from 36 to 18 cm. increased light interception and increased yields by as much as 27% in 1977 and 10% in 1978. However, the taller genotypes remained more productive than short genotypes in each year.

Field photosynthesis of the flag leaves of 11 varieties decreased from anthesis to maturity. Significantly increased photosynthesis occurred after rains, indicating that water stress was a factor in the photosynthetic decrease. Currently-grown productive varieties tended to maintain relatively higher rates of photosynthesis than the old variety Red Chief, which exhibited greater sensitivity to environmental changes. The photosynthetic rate of Red Chief decreased from 40 mg to -6 mg CO_2/dm^2 but, after a rain, increased again to 18 mg CO_2/dm^2. Photosynthesis was plotted against estimated photosynthetic unit density (PSUD) where the photosynthetic unit was the P700-chlorophyll a-protein. Theoretically, PSUD should increase proportionately with photosynthesis. Low photosynthetic rates at high PSUDs indicated an influence of other factors -- possibly limited moisture. Proportionality of photosynthesis and PSUD (1:1 slope) occurred as plants approached maturity and decreased chlorophyll became a limiting factor.

Role of Nitrate Reductase -- Established high protein lines derived from Atlas 66 were demonstrated to consistently exhibit higher levels of nitrate reductase activities than ordinary varieties of wheat by L. Klepper (R-7). In a study of seasonal patterns of nitrate reductase activity in 4 winter varieties differing in grain protein content and with different sources of genes for protein, Lancota, the highest protein variety, had the highest nitrate reductase activity followed by the other high protein varieties and with Centurk the lowest. The NO_3-reductase activity peaked at head emergence in each variety and then decreased slowly until maturity with Lancota maintaining measureable activity longer than the other varieties (Wilhelmi thesis). Several European varieties were found to have activity levels similar to that of Centurk (R-16).

Nap Hal, extensively used in the Nebraska project as a high protein genetic source, was determined to be comprised of at least five distinctly different types based on electrophoretic patterns of the glutenins at the USDA Northern Regional Research Laboratory. NO_3-reductase activity of the 5 types based on seedling analyses ranged from 10.2 for types 1 and 2 to 21.4 for type 5 (R-16).

We conclude from this research that elevated NO_3-reductase activity is necessary for high grain protein in wheat. However, since the reduction of NO_3 is only the first of several enzymatic steps it is probable that these later enzymes could interfere with high protein development. Thus, while high protein varieties require an elevated level of NO_3-reductase activity, not all varieties with elevated NO_3-reductase activity may be high in grain protein content.

OBJECTIVE 6

International Evaluation

An International Winter Wheat Performance Nursery was established in 1969 as a means of evaluating uniformly new winter wheat varieties from the United States and other countries. Each year since 1969 30 varieties have been tested. The number of test sites has grown from 23 in 16 countries in 1969 to 68 in 38 countries in 1980 (Table 18). Additionally, 50 IWWPN observation nurseries were distributed to 35 sites in 19 countries in 1980 (Table 19). A total of 150 varieties from 28 countries have been evaluated during the 12-year period (Table 20). Performance data from reporting sites, after analysis and summarization at Lincoln, Nebraska, have been distributed each year initially in preliminary reports (R-1, R-2, R-4, R-5, R-11, R-12, R-15, R-18, R-20, R-21) and then more fully in Nebraska Research Bulletins (72, 73, 75, 77, 80, 81, 82, 83, 85). The latter have included results of protein and lysine analyses of seed from nursery entries returned to the University of Nebraska Wheat Quality Laboratory by cooperators.

The five most productive varieties in the IWWPN each year since 1969 are identified in Table 21. Their mean yields and protein contents over reporting sites are shown. The Russian variety Bezostaya 1, a check variety in the nursery, has exhibited unusually broad international adaptation and was the most productive variety on the average in 1969, 1970 and 1972. Bezostaya 1 has been among the 5 most productive varieties in 7 out of 11 years from 1969 through 1979. The Sava variety from Yugoslavia was most productive in 1971 and 1973 and was second to Bezostaya 1 in 1972. Partizanka, another Yugoslav variety, was highest yielding in 1979. Talent from France and Yubiley from Bulgaria are the other varieties that were highest yielding during 2-year periods of testing. Centurk and Scout 66 from the Nebraska breeding program were among the highest yielding varieties in 1970 (Scout 66), 1971 and 1973 (Centurk).

Varieties with the highest average protein content in the IWWPN each year from 1969 through 1978 are identified in Table 22. Atlas 66, the high protein check variety in the IWWPN, produced grain with highest protein content in all but three years but was low yielding. Romanian varieties as a group have exhibited high levels of protein in their grain but have not been very productive on an international basis. Only Dacia in 1973 was among the top 5 varieties both in yield and protein content.

It should be pointed out that the newest experimental winter lines from Nebraska, in which high yield and high protein potential have been combined, have not yet been included in the IWWPN. This will occur if funds needed to continue the nursery are provided.

Table 18. International Winter Wheat Performance Nursery sites in 1980 (replicated nurseries).

Site No.	Location	Site No.	Location
8	Afghanistan, Kabul	56	Pakistan, Islamabad
26	Afghanistan, Kunduz	67	Peru, Lima
22	Algeria, Algiers	75	Poland, Przeclaw
42	Argentina, Balcarce	52	Poland, Warszawa
41	Argentina, Bordenave	14	Romania, Fundulea
80	Argentina, Marcus Juarez	63	South Africa, Bethlehem
30	Austria, Vienna	73	South Africa, Pretoria
37	Bulgaria, Tolbukhin	70	Spain, Alcala de Henares
74	Canada, Alberta, Lethbridge	81	Spain, Barcelona
72	Canada, Prince Edward Island	16	Sweden, Svalof
66	Chile, Chillan	32	Switzerland, Zurich
40	Chile, Temuco	78	Syria, Aleppo
44	Czechoslovakia, Male Ripnany	13	Turkey, Ankara
45	Czechoslovakia, Sedlec	59	Turkey, Erzurum
68	East Germany, Boehnshausen	12	Turkey, Eskisehir
31	England, Cambridge	19	USA, California, Davis
34	Finland, Jokioinen	65	USA, Colorado, Akron
51	France, Orgerus	38	USA, Colorado, Fort Collins
33	Hungary, Martonvasar	76	USA, Indiana, Brookston
43	Hungary, Szeged	77	USA, Kansas, Hutchinson
54	Iran, Hamadan	71	USA, Montana, Billings
10	Iran, Karaj	23	USA, Nebraska, Lincoln
79	Iran, Tabriz	24	USA, New York, Ithaca
15	Iraq, Sulaimaniya	17	USA, North Carolina, Rowan Co.
6	Italy, Milano	18	USA, Oklahoma, Stillwater
21	Italy, Rieti	53	USA, Oregon, Corvallis
49	Japan, Morioka Iwate	25	USA, Washington, Pullman
58	Jordan, Amman	48	USSR, Krasnodar
9	Korea, Suwon	64	USSR, Mironovski
55	Lebanon, Beirut	62	USSR, Odessa
47	Mexico, Toluca	28	West Germany, Monsheim
57	Nepal, Kathmandu	29	West Germany, Weihenstephan
4	Netherlands, Wageningen	7	Yugoslavia, Novi Sad
69	Norway, Vollebekk	27	Yugoslavia, Zagreb

Table 19. IWWPN Observation Nurseries distributed since 1973.

Nursery	Year	No. of sets	No. of sites	No. of countries
5th	1973	13	13	7
6th	1974	14	14	8
7th	1975	28	18	10
8th	1976	36	24	13
9th	1977	35	24	13
10th	1978	44	31	17
11th	1979	51	36	19
12th	1980	50	35	19

Evidence that yield advances in winter wheats continue to occur can be seen in Table 23 and Figure 18. Note that the performance of the check varieties Bezostaya 1 and Atlas 66 has remained relatively constant during the 11-year period from 1969 through 1979. Nursery mean yield and the yield of the most productive variety each year have tended to increase slowly since 1970. Despite the yield advances, mean protein content of the nursery has remained essentially unchanged since 1972 (Table 24 and Figure 19).

Beginning with the Fifth IWWPN grown in 1973, northern hemisphere test sites were divided into 5 regions based on similarity of major environmental factors and geographic location. Since then, performance data for nursery entries each year have been analyzed and summarized both internationally and regionally (80, 81, 82, 83, 85). The 5 regions are 1) Northern European, 2) South-Southeastern European, 3) United States, 4) Near Eastern, and 5) Far Eastern. The performance of some varieties was strikingly different in the different regions, whereas other varieties performed relatively well in most or all of the five regions.

The role of measureable soil properties on the performance of the 30 winter wheat varieties grown in the IWWPN at 31 sites during 1975 and 1976 was evaluated by collecting and analyzing soil samples from the rooting profile at each site. Despite substantial variability among nursery sites in soil type, climate, and soil management, 17 to 74% of the variation in grain yield and 20 to 94% in the grain protein content could be explained by the soil variables (36). Lowest grain yields were obtained from soils with pH lower than 6.0 or on highly calcareous soils. Residual mineral N in the soil profile at most nursery sites was more than enough to produce maximum grain yield and protein, but soil P level appeared to be the main factor limiting yields of most cultivars. Soil K had positive influence on grain yield only at sites with <100 ppm exchangeable K and was generally negative in its influence on protein, while soil SO_4-S correlated positively with grain protein. The trace minerals

Zn, Cu, Mn, and Fe appeared to be important for the nutrition of certain cultivars. Winterkill was the main environmental factor depressing yields in some nurseries while seasonal rainfall had low significance or a negative effect on yield and quality.

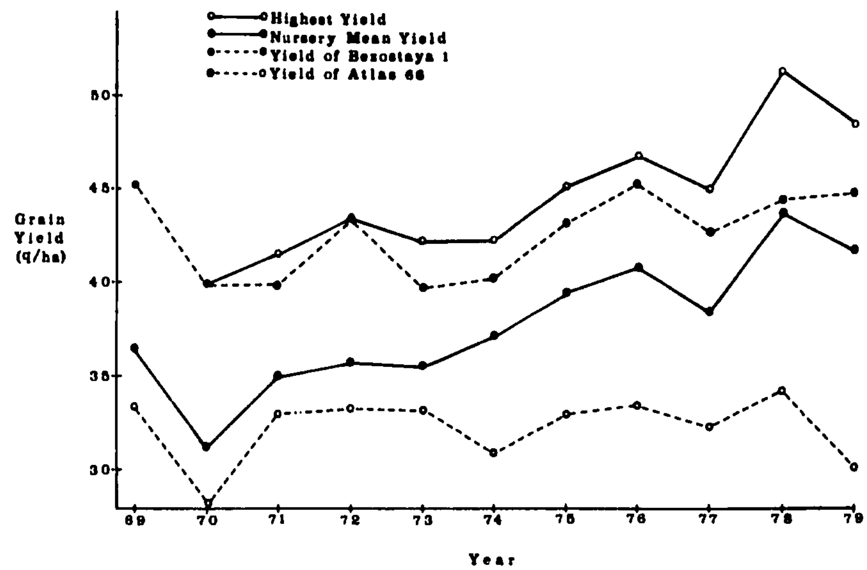


Figure 18. Yield trends among the check varieties Bezostaya 1 and Atlas 66 and experimental varieties in the International Winter Wheat Performance Nursery from 1969 to 1979.

The parameters cultivar mean performance, regression coefficient and regression deviation mean square of individual IWWPN entries on nursery means were computed for agronomic and quality traits to describe variety average performance over environments, variety response to changes in environment, and the predictability of variety response to environmental changes (74). None of the parameters alone adequately described cultivar performance, but together, the three parameters provided useful interpretive information on the general adaptation and performance stability of varieties in the IWWPN.

Table 20.--LIST BY COUNTRY OF VARIETIES AND YEARS GROWN IN THE INTERNATIONAL WINTER WHEAT PERFORMANCE NURSERY (IWWPN) WITH PERMANENT TREATMENT NUMBERS.

Variety	Permanent Treatment Code	Origin	Years Grown
Winalta	0101	Canada	1969, 1970
Lethbridge 1327	0102		1979, 1980
Cappelle Desprez	0201	France	1969, 1970
Talent	0202		1975, 1976
Heine VII	0301	West Germany	1969, 1970, 1971
Caribo	0302		1972, 1973, 1974
Diplomat	0303		1972, 1973, 1974
Jubilar	0304		1974, 1975
Kormoran	0305		1974, 1975
Disponent	0306		1978, 1979
Absolvent	0307		1978, 1979
Bankuti 1201	0401	Hungary	1969, 1970
Fertodi 293	0402		1969, 1970, 1971
Martonvasar 2, (MV69/06)	0403		1969, 1970, 1971
GKF-2	0404		1975, 1976
GKF-8001	0405		1976, 1977
Martonvasar 3, (MV62/12)	0406		1976, 1977
Martonvasari 4, (MV26-72)	0407		1978, 1979
Martonvasari 5	0408		1979, 1980
GK-Protein (GK-Tiszata)	0409		1979, 1980
Martonvasari-6	0410		1980, 1981

Table 20.—(continued)

Variety	Permanent Treatment Code	Origin	Years Grown
San Pastore	0501	Italy	1969, 1970, 1971
Strampelli	0502		1971, 1972, 1973
Victor I	0503		1972, 1973
Marimp 3	0504		1972, 1973, 1974
Demar 4	0505		1974, 1975
Sieve	0506		1975
Flavio	0507		1976, 1977
Inernio	0508		1980, 1981
Inia 66	0601	Mexico	1969, 1970
Lerma Rojo 64	0602		1969-1978, (long term spring check)
Super X	0603		1979-present, (long term spring check)
Felix	0701	Netherlands	1969, 1970, 1971
Clarion	0702		1972, 1973, 1974
Manella	0703		1972, 1973, 1974
Lely	0704		1975, 1976
Clement	0705		1979, 1980
Bastion	0706		1980, 1981
Yung Kwang	0801	South Korea	1969, 1970, 1971
Odin	0901	Sweden	1969, 1970
Starke	0902		1971, 1972, 1973

Table 20.--(continued)

Variety	Permanent Treatment Code	Origin	Years Grown
Atlas 66	1001	USA, NC	1969-present (high protein check)
Benhur	1002	USA, IN	1969, 1970, 1971
Blueboy	1003	USA, NC	1969-present (low protein check)
Gage	1004	USA, NE	1969, 1970
Gaines	1005	USA, WA	1969, 1970
Lancer	1006	USA, NE	1969, 1970
NB67730	1007	USA, NE	1969, 1970
Parker	1008	USA, KS	1969, 1970, 1971
Purdue 4930A6-28-2-1	1009	USA, IN	1969, 1970
Arthur, (Purdue 5752A1-1P-2)	1010	USA, IN	1969, 1970, 1971
Riley 67	1011	USA, IN	1969, 1970
Scout 66	1012	USA, NE	1969, 1970, 1971
Shawnee	1013	USA, KS	1969, 1970
Stadler	1014	USA, MO	1969, 1970
Sturdy	1015	USA, TX	1969, 1970, 1971
Timwin	1016	USA, WI	1969, 1970, 1971
Triumph 64	1017	USA, OK	1969, 1970, 1971
Yorkstar	1018	USA, NY	1969, 1970, 1971
Centurk, (NB66425)	1019	USA, NE	1969, 1971, 1972, 1973
C.I.15074, (NB68513)	1020	USA, NE	1971, 1972, 1973
Tam 102, (TX62A4793-7)	1021	USA, TX	1970, 1971, 1972, 1973
Winter Triticale	1022	USA, NE	1971
Lancota, (NE701132)	1023	USA, NE	1972, 1973, 1974
Blueboy II	1024	USA, NC	1974, 1975
Sentinel	1025	USA, NE	1975, 1976
Oasis	1026	USA, IN	1976, 1977
Sage	1027	USA, KS	1976, 1977
WA5829	1028	USA, WA	1976, 1977
NE68719	1029	USA, NE	1976, 1977
NE73640	1030	USA, NE	1977, 1978
Lindon, (CO-55)	1031	USA, CO	1977, 1978
Ticonderoga	1032	USA, NY	1978, 1979
Nap Hal/Atlas 66	1033	USA, NE	1978, 1979
Newton, (KS73112)	1034	USA, KS	1978, 1979
CI13449/Centurk	1035	USA, NE	1978, 1979
NE7060	1036	USA, NE	1979, 1980
Purdue 6922A1-16	1037	USA, NY	1979, 1980
Houser	1038	USA, NY	1980, 1981
TX 71A562-6	1039	USA, TX	1980, 1981
TX 69A569-1 (TAM W-105)	1040	USA, TX	1980, 1981

Table 20.--(continued)

Variety	Permanent Treatment Code	Origin	Years Grown
Bezostaya 1	1201	USSR	1969-present (long term winter check)
Karlik 1, (Dwarf Bezostaya)	1202		1974, 1975
Aurora	1203		1974, 1975
Kavkaz	1204		1974, 1975
Odesskaya 51	1205		1976, 1977
Priboy	1206		1976, 1977
Krasnodarskaya 39	1207		1977, 1978
Mironovskaya 808	1208		1977, 1978
Odessa 4	1209		1979, 1980
Probstdorfer Extrem	1301	Austria	1971, 1972, 1973
Probstdorfer Karat, (WWP7147)	1302		1976, 1977
NR72/837	1303		1978, 1979
Samson (NR 73/5028)	1304		1978, 1979
Adam	1305		1979, 1980
WWP 4394	1306		1980, 1981
Jyva	1401	Finland	1971, 1972, 1973
Vakka	1402		1971, 1972, 1973
J03057	1403		1979, 1980
Aura	1404		1980, 1981
Hokuei	1501	Japan	1971, 1972, 1973
Kitakami Komugi	1502		1975, 1976
Hackiman-Komugi	1503		1979, 1980

Table 20.--(continued)

Variety	Permanent Treatment Code	Origin	Years Grown
Backa	1601	Yugoslavia	1971, 1972, 1973
Sava, (NS611)	1602		1971, 1972, 1973
NS732	1603		1971, 1974
Zlatna Dolina, (Golden Valley, Zg 5994/66)	1604		1972, 1973, 1974
Sanja (Zg 5996/66)	1605		1974, 1975
Dunav-1	1606		1975, 1976
Biserka	1607		1975, 1976
Zg 887/73	1608		1977, 1978
Zg 4240/73 (Moslavka)	1609		1977, 1978
Zg 4293/73	1610		1977, 1978
Zg 4364/73 (Zlatoklaska)	1611		1977, 1978
Partizanka	1612		1978, 1979
NSR-1	1613		1979, 1980
Maris Nimrod	1701	England	1972, 1973, 1974
Maris Huntsman	1702		1975, 1976
Maris Templar	1703		1975, 1976
Dacia	1801	Romania	1972, 1973, 1974
Moldova	1802		1972, 1973, 1974
Favorit	1803		1974, 1975
F26-70	1804		*1976, 1977
F53-70	1805		1977, 1978
F54-70	1806		1977, 1978
Iulia	1807		1977, 1978
Lovrin 24	1808		1979, 1980
F80-73 (Doina)	1809		1979, 1980
Zenith	1901	Switzerland	1972, 1973, 1974

*F26-67 by mistake was used.

Table 20.—(continued)

Variety	Permanent Treatment Code	Origin	Years Grown
Rousalka	2001	Bulgaria	1972, 1973, 1974
Burgas 2, (Sort 12-13)	2002		1974, 1975
Sadovo-1	2003		1977, 1978
Slavyanka	2004		1978, 1979
Yubiley, (2109-36)	2005		1977, 1978
Trakia	2006		1980, 1981
Kirac 66	2101	Turkey	1972, 1973, 1974
Bolal	2102		1974, 1975
Lilifen	2201	Chile	1972, 1973
Carifen 12	2202		1972, 1973, 1974
Likafen	2203		1974, 1975
Galiafen	2204		1976, 1977
Budifen, (Temu-149-73)	2205		1978, 1979
Huenufen	2206		1980, 1981
TRS 237	2301	Australia	1975, 1976
Rashid	2401	Iran	1975, 1976
Bordenave Puan Sag	2501	Argentina	1976, 1977
Slavia, (ST-VUR-37)	2601	Czechoslovakia	1978, 1979

Table 20.--(concluded)

Variety	Permanent Treatment Code	Origin	Years Grown
Jana	2701	Poland	1980, 1981
Kopara	2801	New Zealand	1980, 1981
Alcedo	2901	East Germany	1980, 1981

Table 21. Identity and origin of the five highest yielding varieties in the IWWPN each year from 1969 to 1979.

1969

Variety	Origin	Yield q/ha	Protein %
Number of sites		16	18
Bezostaya 1	USSR	45.2	13.4
Blueboy	USA, NC	43.5	13.6
San Pastore	Italy	41.1	13.6
Sturdy	USA, TX	40.5	14.3
Timwin	USA, WI	39.9	14.1
Nursery mean (28 varieties)		36.6	14.4

1970

Variety	Origin	Yield q/ha	Protein %
Number of sites		32	25
Bezostaya 1	USSR	39.9	14.1
Timwin	USA, WI	36.9	15.1
Arthur	USA, IN	35.7	15.1
Scout 66	USA, NE	35.4	14.8
Parker	USA, KS	34.6	15.0
Nursery mean (28 varieties)		31.1	15.3

1971

Variety	Origin	Yield q/ha	Protein %
Number of sites		28	22
Sava	Yugoslavia	41.5	15.0
Blueboy	USA, NC	40.5	14.2
Bezostaya 1	USSR	39.8	14.5
Timwin	USA, WI	39.0	15.3
Centurk	USA, NE	38.9	14.7
Nursery mean (29 varieties)		35.0	15.3

Table 21.--(continued)

1972			
Variety	Origin	Yield q/ha	Protein %
Number of sites		36	24
Bezostaya 1	USSR	43.4	13.2
Sava	Yugoslavia	42.3	13.4
Dacia	Romania	41.9	14.4
Probstdorfer Extrem	Austria	41.6	13.5
Zlatna dolina	Yugoslavia	40.8	13.2
Nursery mean (29 varieties)		35.8	13.9

1973			
Variety	Origin	Yield q/ha	Protein %
Number of sites		48	31
Sava	Yugoslavia	42.2	13.5
Blueboy	USA, NC	40.7	12.4
Centurk	USA, NE	40.3	14.0
Maris Nimrod	England	40.0	13.4
Rousalka	Bulgaria	39.9	14.0
Dacia	Romania	39.9	14.9
Nursery mean (29 varieties)		35.6	14.2

1974			
Variety	Origin	Yield q/ha	Protein %
Number of sites		45	35
Kavkaz	USSR	42.1	15.0
Aurora	USSR	41.9	14.9
Maris Nimrod	England	40.7	13.4
Burgas 2	Bulgaria	40.3	15.1
Bezostaya 1	USSR	40.2	14.2
Nursery mean (29 varieties)		37.1	14.5

Table 21.--(continued)

1975			
Variety	Origin	Yield q/ha	Protein %
Number of sites		44	35
Talent	France	45.1	14.0
Aurora	USSR	43.9	14.6
Blueboy	USA, NC	43.6	12.5
Bezostaya 1	USSR	43.1	14.0
GK˙ -2	Hungary	43.0	13.8
Nursery mean (29 varieties)		39.6	14.3

1976			
Variety	Origin	Yield q/ha	Protein %
Number of sites		50	33
Talent	France	46.8	14.0
Priboy	USSR	46.2	13.3
Probstdorfer Karat	Austria	46.0	14.1
MV-2	Hungary	45.8	14.4
Blueboy	USA, NC	45.7	12.7
Nursery mean (29 varieties)		40.9	14.2

1977			
Variety	Origin	Yield q/ha	Protein %
Number of sites		56	40
Yubiley	Bulgaria	45.0	13.8
Sadovo-1	Bulgaria	43.2	13.6
Priboy	USSR	42.7	13.6
Bezostaya 1	USSR	42.7	14.1
Probstdorfer Karat	Austria	42.1	14.2
Nursery mean (29 varieties)		38.4	14.4

Table 21.--(concluded)

1978			
Variety	Origin	Yield q/ha	Protein %
Number of sites		53	39
Yubiley	Bulgaria	48.9	13.6
NR 72/837	Austria	48.6	13.9
Slavia	Czechoslovakia	47.5	12.9
MV-4	Hungary	47.3	14.1
Sadovo-1	Bulgaria	46.9	13.4
Nursery mean (29 varieties)		42.3	14.1

1979		
Variety	Origin	Yield q/ha
Number of sites		36[1/]
Partizanka	Yugoslavia	48.3
Lovrin 24	Romania	47.7
MV-4	Hungary	46.9
Doina	Romania	46.3
Slavia	Czechoslovakia	46.0
Nursery mean (29 varieties)		41.8

[1/] Based on reporting sites for preliminary report.

Table 22. Identity and origin of the five varieties with highest grain protein content in the IWWPN each year from 1969 to 1978.

1969			
Variety	Origin	Protein %	Yield q/ha
Number of sites		18	16
Atlas 66	USA, NC	17.5	33.4
Purdue 4930A6-28-2-1	USA, IN	16.6	32.9
NB67730	USA, NE	16.4	34.8
Cappelle Desprez	France	16.0	32.0
Odin	Sweden	15.4	26.7
Nursery mean		14.4	36.6

1970			
Variety	Origin	Protein %	Yield q/ha
Number of sites		25	32
Atlas 66	USA, NC	19.3	28.0
Purdue 4930A6-28-2-1	USA, IN	18.3	28.1
NB67730	USA, NE	17.2	29.1
Cappelle Desprez	France	16.0	26.2
Bankuti 1201	Hungary	15.8	29.1
Nursery mean		15.3	31.1

1971			
Variety	Origin	Protein %	Yield q/ha
Number of sites		22	28
Atlas 66	USA, NC	18.1	33.0
Winter Triticale	USA, NE	17.4	29.2
NB68513	USA, NE	16.5	31.6
Fertodi 293	Hungary	16.2	34.8
Backa	Yugoslavia	16.1	37.4
Nursery mean		15.3	35.0

Table 22.--(continued)

1972			
Variety	Origin	Protein %	Yield q/ha
Number of sites		24	36
Atlas 66	USA, NC	16.5	33.1
Lancota	USA, NE	15.3	37.3
C.I.15074	USA, NE	15.2	32.3
Lilifen	Chile	15.0	31.8
Moldova	Romania	14.7	37.5
Nursery mean		13.9	35.8

1973			
Variety	Origin	Protein %	Yield q/ha
Number of sites		48	31
Atlas 66	USA, NC	16.7	33.2
C.I.15074	USA, NE	15.7	32.4
Lancota	USA, NE	15.5	37.5
Moldova	Romania	15.2	36.0
Dacia	Romania	14.9	39.9
Nursery mean		14.2	35.6

1974			
Variety	Origin	Protein %	Yield q/ha
Number of sites		35	45
Atlas 66	USA, NC	16.9	30.8
Lancota	USA, NE	16.0	33.9
Moldova	Romania	15.9	34.7
Dacia	Romania	15.6	38.6
Favorit	Romania	15.5	37.9
Nursery mean		14.5	37.1

Table 22.--(continued)

1975			
Variety	Origin	Protein %	Yield q/ha
Number of sites		35	44
Sieve	Italy	17.0	30.3
Atlas 66	USA, NC	16.6	33.0
Sentinel	USA, NE	15.6	38.9
Rashid	Iran	15.1	24.7
Favorit	Romania	15.1	39.6
Nursery mean		14.3	39.6

1976			
Variety	Origin	Protein %	Yield q/ha
Number of sites		33	50
Atlas 66	USA, NC	16.6	33.3
Sentinel	USA, NE	15.8	40.2
Bordenave Puan Sag	Argentina	15.8	36.5
Sage	USA, NE	15.2	40.4
Rashid	Iran	15.0	27.1
TRS 237	Australia	15.0	38.2
Oasis	USA, IN	15.0	37.6
Nursery mean		14.2	40.9

1977			
Variety	Origin	Protein %	Yield q/ha
Number of sites		40	56
F26-70	Romania	16.7	36.5
Atlas 66	USA, NC	16.6	32.2
Bordenave Puan Sag	Argentina	15.8	32.6
F54-70	Romania	15.7	37.7
NE73640	USA, NE	15.6	35.9
Nursery mean		14.4	38.4

Table 22.--(concluded)

1978			
Variety	Origin	Protein %	Yield q/ha
Number of sites		53	39
Nap Hal/Atlas 66	USA, NE	18.2	28.4
Atlas 66	USA, NC	16.3	32.3
F53-70	Romania	15.5	41.6
F54-70	Romania	15.5	39.9
NE73640	USA, NE	15.0	38.8
Nursery mean		14.1	42.3

Table 23. Yield (q/ha) trends measured in the International Winter Wheat Performance Nursery from 1969 to 1979.

	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Number of reporting sites	16	32	28	36	48	45	44	50	56	40	36
Highest cultivar mean	45.2 Bezostaya 1	39.9 Bezostaya 1	41.5 Sava	43.4 Bezostaya 1	42.2 Sava	42.1 Kavkaz	45.1 Talent	46.8 Talent	45.0 Yubiley	51.2 Yubiley	48.3 Partizanka
Nursery mean	36.6	31.1	35.0	35.8	35.6	37.1	39.6	40.9	38.4	43.8	41.8
Bezostaya 1	45.2	39.9	39.8	43.4	39.7	40.2	43.1	45.3	42.7	44.5	44.7
Atlas 66	33.4	28.0	33.0	33.1	33.2	30.8	33.0	33.3	32.2	34.1	30.2

Table 24. Grain protein content (%) measured at sites in the International Winter Wheat Performance Nursery from 1969 to 1978.

	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
Number of reporting sites	18	25	22	24	31	35	35	33	40	39
Highest cultivar mean	17.5 Atlas 66	19.3 Atlas 66	18.1 Atlas 66	16.5 Atlas 66	16.7 Atlas 66	16.9 Atlas 66	17.0 Sieve	16.6 Atlas 66	16.7 F26-70	18.2 Nap Hal/ Atlas 66
Nursery mean	14.4	15.3	15.3	13.9	14.2	14.5	14.3	14.2	14.4	14.1
Atlas 66	17.5	19.3	18.1	16.5	16.7	16.9	16.6	16.6	16.6	16.3
Bezostaya 1	13.4	14.1	14.5	13.2	14.1	14.2	14.0	13.9	14.1	14.1
Blueboy	13.6	14.6	14.2	12.3	12.4	12.9	12.5	12.7	12.6	12.7

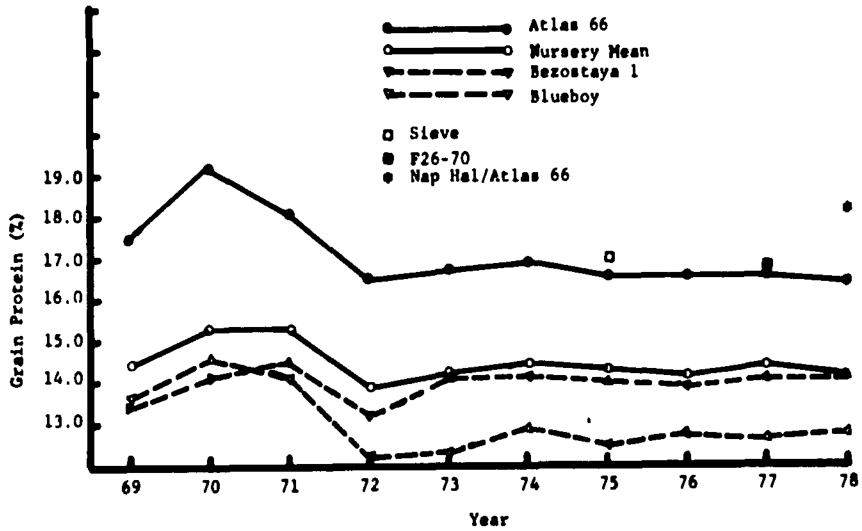


Figure 19. Protein values for selected varieties and the nursery $\bar{x}$ in the International Winter Wheat Performance Nursery from 1969 to 1978.

OBJECTIVE 7

Germplasm Development and Distribution

Germplasm and Publication Requests -- Germplasm and research information from the Nebraska project have been widely distributed. From 1966, seed requests from breeders, agronomists and other researchers totaled 544. In response to these requests high protein-high lysine germplasm was sent to scientists and agriculturalists in the following 46 countries:

- Afghanistan
- Algeria
- Argentina
- Austria
- Australia
- Brazil
- Bulgaria
- Canada
- Chile
- Czechoslovakia
- Denmark
- Ecuador
- Egypt
- England
- Ethiopia
- Federal Republic of Germany
- France
- German Democratic Republic
- Greece
- Hungary
- India
- Italy
- Israel
- Japan
- Korea
- Lebanon
- Lesotho
- Mexico
- Nepal
- Netherlands
- New Zealand
- Norway
- Pakistan
- Peru
- Poland
- Romania
- Saudi Arabia
- South Africa
- Spain
- Sweden
- Switzerland
- Tunisia
- Turkey
- USA
- USSR
- Yemen
- Yugoslavia

Requests for publications from the Nebraska project since 1966 totaled 1090 and have gone to scientists in every country, including the People's Republic of China, in which there is interest in wheat. In addition to requests for publications, project progress reports and Nebraska Research Bulletins on the IWWPN and High Protein-High Lysine Observation Nurseries have been sent routinely to several hundred scientists on our mailing list. Similarly, the Proceedings of 4 International Wheat Conferences were distributed to participants and libraries and to many others who have requested them.

The High Protein-High Lysine Observation Nurseries -- A second principal means of distributing promising germplasm from the Nebraska project was initiated in 1974 with the distribution of experimental lines in a High Protein-High Lysine Observation Nursery to cooperators at selected sites throughout the world. The First Observation Nursery sent to these cooperators in the summer of 1974 contained both spring habit and winter habit experimental wheats. Subsequent to 1974 winter and spring wheats have been distributed in separate nurseries. Sites and countries to which the Winter Wheat High Protein-High Lysine Observation Nurseries were sent from 1976 through 1980 are identified in Table 25. Materials included in the winter observation nurseries in 1979 and in 1980 are listed in Tables 26 and 27.

Sites to which the Spring Wheat Observation Nurseries have been sent since 1976 appear in Table 28. The experimental spring wheats included in the nurseries in 1979 and 1980 are listed in Tables 29 and 30.

Both the spring and winter wheat observation nurseries have been grown as replicated nurseries at Yuma, AZ and/or Lincoln, NE to provide reliable information on both yield performance and grain protein content. Cooperators to whom the observation nurseries have been sent were encouraged to send seed samples of harvested plots to our laboratory in Lincoln for protein and lysine analyses. This information for the observation nurseries grown in 1975 and 1976 was published as Nebraska Research Bulletins 282 and 291 (84, 86).

Cooperators growing these nurseries are urged to identify the most promising lines under their production environments either for direct use or for hybridization with their best domestic varieties. Although there has been relatively little feed-back of information on the use of these materials, we believe that many cooperators are routinely utilizing the best lines in crosses.

New Varieties -- For more than 10 years Bezostaya 1 has been an important variety in Turkey -- particularly in Thrace and Western Anatolia. The superior performance of Bezostaya 1 in the IWWPN at sites in Turkey as well as at most other test sites throughout the world contributed strongly to early recognition of its potential value for Turkey and its wide scale commercial use in that country (72, 73, 75, 76).

More recently the variety Bolal has assumed increasing importance as a commercial winter wheat variety on the Anatolian Plateau of Turkey, where much of that country's wheat is produced. Bolal is a stem rust-resistant selection from the Nebraska breeding program that was initially observed at Eskisehir, Turkey in the International Rust Nursery. Subsequent testing of Bolal in state nurseries in Turkey and in the IWWPN established its productivity and rust resistance in Anatolia and led to its naming and registration in Turkey. Bolal currently is reported to be a leading winter variety, if not the leading variety, in Anatolia. Together, Bezostaya 1 and Bolal have contributed enormously to increased and stable wheat production in Turkey.

The high protein Lancota variety selected in Nebraska from the cross Atlas 66/Comanche//Lancer has achieved limited popularity among growers in Nebraska, Kansas, Texas and South Dakota (34). Although it combines field resistance to leaf and stem rust with excellent yield and protein potential, its tall straw, relatively late maturity, and somewhat erratic performance in commercial production have tended to limit its popularity and use in central USA. It is being utilized for breeding purposes by winter wheat breeders in several states and in other countries including the Plant Breeding Institute at Cambridge, England.

Another line derived from a cross involving Atlas 66 as a high protein donor parent was selected in the German Democratic Republic by A. Meinel (personal communication). The line has shown a promising combination of yield potential, elevated protein, straw strength and disease resistance. In trials up to 1979 the line was equal to or higher yielding than Alcedo, the leading variety in the GDR, and was significantly higher than Alcedo in grain protein content. It is not known whether the new line has been approved for registration in the GDR.

The winter variety Belinda was named and released by the Republic of South Africa and currently occupies a small but important (2-3%) acreage at the higher elevations in that country (18). Belinda is a stem rust-resistant selection from the Nebraska breeding program initially tested in South Africa as a Nebraska entry in the International Rust Nursery. It exhibited rust resistance, productivity and good adaptation to wheat production conditions in subsequent performance evaluation in South Africa.

In 1971 26 lines derived from crosses of Atlas 66 with hard red winter wheats at Nebraska were publically released as high protein germplasm. All combined high protein with leaf rust resistance and some tolerance to stem rust. Six of the lines were resistant to Soil-Borne Mosaic (9).

Largely as a result of the USDA-Nebraska research on wheat protein there now is an awareness among wheat breeders that protein content is an inherited trait and can be manipulated genetically. Many wheat breeding programs in the USA and other countries now include higher protein as a breeding objective and routinely evaluate early generation selections for protein. From this collective effort will come an increasing number of new varieties in which high productivity, disease resistance, short straw, and other acceptable agronomic traits are combined with elevated grain protein content and improved nutritional value.

Table 25. Sites and years in which High Protein-High Lysine Winter Wheat Observation Nurseries were evaluated.

Country	Station	1976	1977	1978	1979	1980
Afghanistan	Kabul	X	X	X	X	X
Afghanistan	Kunduz	X	X	X	X	X
Argentina	Balcarce	X	X	X	X	X
Argentina	Bordenave	X	X	X	X	X
Argentina	Tres Arroyos		X		X	X
Brazil	Passo Fundo	X	X	X	X	X
Chile	Temuco	X	X	X	X	X
Czechoslovakia	Stupice				X	X
East Germany	Bohnshausen				X	X
Ecuador	Quito	X	X	X	X	X
France	Champigny en Beauce				X	X
France	Orgerus		X			
Hungary	Martonvasar	X	X	X	X	X
India	New Delhi	X	X	X	X	X
India	Simla	X	X	X	X	X
Iran	Hamadan	X	X	X	X	
Iran	Karaj	X	X	X	X	
Iran	Tehran				X	
Iraq	Sulaimaniya	X	X	X		X
Israel	Tel-Aviv				X	X
Italy	Bologna		X	X	X	X
Italy	Milano			X	X	X
Jordan	Amman	X	X	X	X	X
Korea	Suwon	X	X	X	X	X
Lebanon	Beirut	X	X			
Mexico	Toluca	X	X	X	X	X
Nepal	Kathmandu	X	X	X	X	X
New Zealand	Gore			X	X	X
Peru	Lima	X	X	X	X	X
South Africa	Pretoria	X	X	X	X	X
Spain	Logrono	X	X	X	X	X
Syria	Aleppo		X	X	X	X
Turkey	Ankara	X	X	X	X	X
Turkey	Erzurum	X	X	X	X	X
Turkey	Eskisehir	X	X	X	X	X
USA	Yuma, AZ	X	X	X	X	X
USA	Lincoln, NE	X	X	X	X	X
USA	Manhattan, KS			X	X	
USA	Stillwater, OK	X	X	X	X	X
USA	Corvallis, OR	X	X	X	X	X

Table 26.

1978 - 1979

HIGH PROTEIN-HIGH LYSINE WINTER WHEAT OBSERVATION NURSERY

University of Nebraska - Lincoln

(113 Entries)

Permanent number	Pedigree	Seed source	Entry no.	Yield1/ (q/ha)	Grain protein1/ (%)
	Centurk	78M P.S.	1	33.2	16.5
	Lancota	P.S.	2		
	CI 13449		3		
71836	Ciano F67/22A	78Y 10632	4	43.8	17.9
721229	At166/Nap Hal//NB68570/Centurk	10982	5	51.2	17.5
"	"	10983	6	44.7	17.6
721230	At166/Nap Hal//TX62A2522-1-4	10738	7	44.3	16.7
"	"	10743	8	37.3	17.9
"	"	10747	9	50.5	16.8
721235	At166/Nap Hal//Lancota/Likafen	10994	10	41.1	17.3
"	"	10995	11	31.5	18.1
"	"	11004	12	47.9	17.1
"	"	11010	13	45.4	17.2
"	"	11011	14	37.2	17.6
"	"	11012	15	41.7	17.3
"	"	11013	16	36.5	17.4
721236	At166/Nap Hal//TX62A2522-1-4	10836	17	45.1	17.9
"	"	10840	18	46.0	17.3
"	"	10841	19	45.5	18.2
"	"	10842	20	42.8	17.9
"	"	10880	21	45.8	17.8
"	"	11024	22	45.2	17.4
"	"	11026	23	37.9	18.5
"	"	11031	24	49.3	17.4
"	"	11032	25	45.0	17.2
"	"	11033	26	42.2	17.5
"	"	11037	27	51.3	17.2
"	"	11042	28	42.3	17.8
"	"	11048	29	45.3	17.8
"	"	11050	30	46.6	17.5
721238	At166/Nap Hal//Skorospelka 35/NE701137	10075	31	37.1	23.3
"	"	10613	32	30.1	20.0
"	"	10846	33	36.1	22.1
"	"	10847	34	49.1	20.5
"	"	10915	35	33.7	19.8

1/ Yield and protein data are mean values from a 2-replication nursery grown at Yuma, Arizona, USA, in 1978.

Table 26 (continued)

Permanent number	Pedigree	Seed source	Entry no.	Yield[1/] (q/ha)	Grain protein[1/] (%)
721240	At166/Nap Hal//NE701139/Dwf. Bezostaya	78Y 10890	36	35.0	18.8
721241	At166/Nap Hal//Likafen/NE701134	10627	37	30.1	20.4
"	"	10775	38	39.5	18.2
"	"	10893	39	39.6	18.5
721242	At166/Nap Hal//Rousalka/NE701134	10853	40	35.2	17.9
721244	At166/Nap Hal//F226-68/Lancota	11056	41	38.5	18.6
721251	At166/Nap Hal//Likafen/NE701134	10752	42	21.0	18.7
721347	At166/Nap Hal//Norde Desprez 2	10787	43	36.3	19.2
"	"	10790	44	51.6	17.0
"	"	10805	45	39.8	18.4
"	"	10926	46	43.1	17.1
721350	At166/Nap Hal//NE701136/Blueboy	10770	47	31.0	21.3
721351	At166/Nap Hal//Bezostaya 1	10030	48	37.6	18.2
"	"	10032	49	24.1	20.5
"	"	10104	50	32.7	20.4
	Centurk		51	33.2	16.5
	Lancota		52		
	CI 13449		53		
721352	At166/Nap Hal//Bezostaya 1	10589	54	35.4	18.1
721354	At166/Nap Hal//NE701154/Skorospelka 35	10815	55	23.9	19.7
721358	At166/Nap Hal//Carifen 12	11057	56	38.8	17.6
721419	Nap Hal/At166/4/Likafen/3/At166/Cmn/2/ Hume	11062	57	38.6	18.4
"	"	11063	58	31.0	19.4
"	"	11069	59	42.3	17.3
721424	Nap Hal/At166//NB68510/Hyslop	10820	60	48.2	16.9
"	"	10822	61	33.0	17.3
"	"	10934	62	29.6	19.9
721428	Nap Hal/At166//Lovrin 12	10013	63	26.7	17.8
721434	Nap Hal/At166//Sort 12-13	10767	64	33.5	18.8
"	"	10904	65	33.4	20.2
73604	Nap Hal/At166//2*Aurora	10634	66	35.6	19.9
"	"	11090	67	38.8	17.5
73608	Nap Hal/At166//CI 13447	11091	68	29.0	18.0
73610	"	11094	69	25.8	18.1
"	"	11095	70	29.9	17.5
73624	Nap Hal/At166/Krasnodarskaya 39	10245	71	28.4	18.1
73631	Nap Hal/At166/CI 13449	11133	72	36.4	16.9
"	"	11136	73	42.7	17.2
73649	Nap Hal/CR8156//NB68719	10261	74	33.6	18.7
73687	Nap Hal/Lancer//CB96/Nazareth/3/F73-71	11165	75	42.5	17.1
73699	Kitakomi-Komugi/3/Nap Hal/Lancer/2/ SD69107	11170	76	43.9	17.5
73702	Dunav-1/3/Nap Hal/Lancer/2/Bezostaya 1	11178	77	32.3	19.2
"	"	11180	78	32.9	19.0
73704	Dunav-1/3/NE701136/NS11-53/2/NB68570/ Aurora	11184	79	41.0	18.2
73709	GKT-8001//Nap Hal/CI 13449	10295	80	46.9	14.0
"	"	10648	81	36.2	16.1

Table 26 (concluded)

Permanent number	Pedigree	Seed source	Entry no.	Yield[1/] (q/ha)	Grain protein[1/] (%)
73710	GKT-8001/3/Nap Hal/Lancer//NE701136/ Centurk	78Y 11212	82	32.8	17.8
"	"	11214	83	27.3	18.0
"	"	11216	84	30.9	17.4
"	"	11224	85	29.8	17.3
73712	Kiszombori-1/3/SD69111/2/NE701136/ Centurk	11233	86	43.8	17.3
73713	GK-Fertodi-2/NE701134	11237	87	44.3	17.0
73730	Burgas 2/3/Nap Hal/Lancer/2/NE701136/ Centurk	11258	88	33.0	18.0
73731	Burgas 2//Nap Hal/CI 13449	10707	89	40.1	16.6
73735	Rousalka/3/Nap Hal/Trader/2/NS974/NB69566	11263	90	34.2	17.1
73736	Lilifen//Nap Hal/Trader	11273	91	40.8	17.5
73748	Skorospelka 35/3/Nap Hal/Lancer/2/ Dwf. Bezostaya/NE701134	10337	92	49.2	16.4
73749	Skorospelka 35/2/Nap Hal/CI 13449	11284	93	35.9	17.7
73751	Blueboy II//Nap Hal/CI 13449	11286	94	62.5	14.8
73752	NB68719//Nap Hal/CI 13449	11290	95	41.2	16.7
"	"	11294	96	45.1	16.5
73753	"	11309	97	42.4	17.1
73762	Greece 78310-A-3/Bez. 1/3/Nap Hal/Lancer/2/ Homestead/Bezostaya 1	11337	98	27.7	18.6
73771	CI 13449/TAM 102	11344	99	36.1	15.4
73816	F126-71/3/Nap Hal/Lancer/2/ID0032	10361	100	47.1	16.9
	Centurk		101	33.2	16.5
	Lancota		102		
	CI 13449		103		
73819	NS447/3/Nap Hal/Lancer/2/NE701136/Lovrin 13	10685	104	37.3	17.8
73820	NS447/3/Nap Hal/Lancer/2/F226-68/NB69566	10686	105	28.3	17.6
73827	SD69103/2/Dwf. Bezostaya/NE701134/3/ Nap Hal/CI 13449	11412	106	40.4	16.4
"	"	11417	107	40.2	16.9
73838	Kiszombori-1//Nap Hal/CI 13449	11428	108	43.7	17.4
"	"	11432	109	40.6	17.1
"	"	11433	110	42.5	17.1
73860	TX65A1503-1//Nap Hal/CI 13449	11458	111	48.6	16.3
73878	Nap Hal/CI 13449//Centurk	11472	112	50.6	15.8
73885	F53-70//Nap Hal/CI 13449	11490	113	46.3	17.0

Table 27.
1979 - 1980

HIGH PROTEIN-HIGH LYSINE WINTER WHEAT OBSERVATION NURSERY

(85 Entries)

Permanent Number	Variety or Pedigree	1979 Yuma Source	Entry No.
Check	Bennett	---	1
Check	Lancota	---	2
	Local Check	---	3
721224	Atlas 66/Nap Hal//NE 701152/Aurora	90406	4
"	"	90407	5
"	"	90509	6
"	"	90513	7
721232	Atlas 66/Nap Hal//Bezostaya 1	90514	8
721241	Atlas 66/Nap Hal//Likafen/NE 701134	90410	9
"	"	90411	10
7212[illegible]2	Atlas 66/Nap Hal//Rousalka/NE 701134	90518	11
721350	Atlas 66/Nap Hal//NE 701136/Blueboy	90515	12
721351	Atlas 66/Nap Hal//Bezostaya 1	90029	13
721355	Atlas 66/Nap Hal//Rannaya/NE 701136	90033	14
721428	Nap Hal/Atlas 66//Lovrin 12	90038	15
721434	Nap Hal/Atlas 66//Sort 12-13	90415	16
73604	Nap Hal/Atlas 66//2*Aurora	90418	17
73608	Nap Hal/Atlas 66//CI 13447	90419	18
73612	Nap Hal/Atlas 66//Sanja	90421	19
73648	Nap Hal/CR 8156//Aurora	90075	20
"	"	90079	21
73649	Nap Hal/CR 8156//NB 68719	90529	22
"	"	90530	23
73676	Nap Hal/Tr[illegible]der/3/Nord Desprez/2*Sel. 101 Cor. 63-130-66-5[illegible]/Sa[illegible]a/4/Dunav-1	90533	24
73685	Nap Hal/[illegible]cer//Dwf. Bezostaya/3/NS 622	90534	25
"	"	90537	26
73687	Nap Hal/Lancer/2/CB 96/Nazareth/3/F73-71	90540	27
73701	Dunav-1/3/Nap Hal/Trader//NS 732	90427	28
73702	Dunav-1/3/Nap Hal/Lancer/2/Bezostaya 1	90543	29
73704	Dunav-1/3/NE 701136/NS 11-53/2/NB 68570/Aurora	90130	30
"	"	90131	31
"	"	90136	32
"	"	90137	33
"	"	90145	34
"	"	90545	35
73735	Rousalka/3/Nap Hal/Trader/2/NS 974/NB 69566	90548	36
73786	Nap Hal/CI 13449//Burgas 2	90150	37
"	"	90151	38
"	"	90157	39
"	"	90158	40
Check	NE 7060	---	41
Check	Atlas 66	---	42
Check	F26-70	---	43
741101	Nap Hal/Atlas 66//Kavkaz/3/TJB 54-224	90553	44
"	"	90556	45

Table 27 (concluded)

Permanent Number	Variety or Pedigree	1979 Yuma Source	Entry No.
741101	Nap Hal/Atlas 66//Kavkaz/3/TJB 54-224	90558	46
"	"	90559	47
741223	Nap Hal/Atlas 66//Capitol	90190	48
741247	Nap Hal/Atlas 66//Sava	90583	49
"	"	90584	50
"	"	90588	51
741252	Nap Hal/Atlas 66//Lilifen/Krasnodarskaya 39	90589	52
"	"	90590	53
"	"	90591	54
741265	Nap Hal/CI 13449//NS 12-56	90194	55
741299	Nap Hal/CI 13449//Martonvasari 2	90216	56
741304	Nap Hal/CI 13449/4/Burgas 2/3/Nap Hal/Lancer//NE 701134/ Parker	90295	57
741312	Nap Hal/CI 13449/3/CC-INIA/2/CNO-7 Cerros	90281	58
741338	Nap Hal/Atlas 66//NS 10-18	90223	59
741349	Nap Hal/Atlas 66//NS 10-18	90561	60
741357	Nap Hal/Atlas 66//Hardi	90566	61
741360	Nap Hal/Atlas 66//Talent	90228	62
"	"	90569	63
741384	Nap Hal/CI 13449//Talent	90450	64
741395	Nap Hal/CI 13449//Martonvasari 2	90246	65
741417	Nap Hal/CR 8156//TX 62A4793-7/NB 66403	90573	66
741425	Nap Hal/CR 8156//NS 11-33	90441	67
"	"	90444	68
"	"	90605	69
741426	Nap Hal/CR 8156//Talent	90578	70
"	"	90579	71
"	"	90581	72
741427	Nap Hal/CR 8156//F75-71	90298	73
"	"	90299	74
"	"	90300	75
"	"	90306	76
"	"	90307	77
"	"	90308	78
"	"	90461	79
741430	TJB 54-224//Nap Hal/CI 13449	90606	80
741431	Rn 12/Tob-Cno//NS 622/3/Nap Hal/Atlas 66	90620	81
"	"	90621	82
Check	Bennett	---	83
Check	Lancota	---	84
	Local Check	---	85

Table 28. Sites and years in which High Protein-High Lysine Spring Wheat Observation Nurseries were evaluated.

Country	Station	1976	1977	1978	1979	1980
Afghanistan	Kabul	X	X	X	X	X
Afghanistan	Kunduz	X	X	X	X	X
Algeria	Algiers	X	X	X	X	
Argentina	Tres Arroyos		X	X	X	X
Australia	New South Wales			X		
Brazil	Passo Fundo	X	X	X	X	X
Brazil	Sao Paulo	X	X	X	X	
Chile	Santiago	X	X	X	X	X
Ecuador	Quito			X	X	X
Egypt	Alexandria				X	X
Egypt	Cairo		X			
India	New Delhi	X	X	X	X	X
India	New Delhi				X	X
Iran	Karaj	X	X	X	X	
Iraq	Sulaimaniya	X	X	X	X	X
Italy	Bologna		X			
Italy	Milano			X	X	X
Italy	Rieti	X	X	X	X	X
Jordan	Amman	X	X	X	X	X
Jordan	Amman			X	X	X
Lebanon	Beirut	X				
Nepal	Bhairahawa				X	X
New Zealand	Gore			X	X	X
Pakistan	Islamabad	X	X	X	X	X
Pakistan	Lyallpur			X	X	X
Spain	Madrid	X	X	X	X	X
USA	Yuma, AZ	X	X	X	X	X
USA	Davis, CA	X	X	X	X	X

Table 29.
1978 - 1979

HIGH PROTEIN-HIGH LYSINE SPRING WHEAT OBSERVATION NURSERY

University of Nebraska - Lincoln

(105 Entries)

Permanent number	Pedigree	Seed source	Entry no.	Yield[1/] (q/ha)	Grain protein[1/] (%)
	Super X	78Y 50201	1	48.7	14.4
	Local Check		2		
	Era	70202	3		
	CNO-7 Cerros/No. 66-Tiba	10404	4	42.9	18.3
	No. 66/Gallo	10406	5	45.2	18.8
	CNO/Son 64-Kl. Rend/CNO'S'-No. 66	10409	6	38.2	17.9
	Tob-CNO'S'/Tob-8156//Bb(18M)CM5403-8PY-1PB	10413	7	41.0	18.0
	"	10422	8	41.5	18.5
	"	10423	9	42.3	18.5
	"	10427	10	40.4	18.6
	"	10430	11	43.5	18.8
	"	10431	12	42.7	18.3
	"	10435	13	38.8	18.4
	(Cal/CC-8156/CNO'S')Cal-Sar, CM-5756-7PY-1PB	10448	14	50.6	18.9
	"	10455	15	46.7	18.6
	"	10459	16	42.7	19.1
	Tob-Turpin/No. 66, CM5214-A-1PY-1PB	10464	17	48.8	19.6
	"	10465	18	47.2	19.5
	"	10469	19	47.4	19.0
	"	40477	20	46.4	19.8
	Bb-CNO//CNO/LR64^2-SR64, RN-CM5437-19PY-8PB	10481	21	43.2	18.1
	(Cal/CC-8156 x CNO'S')CNO'S'-8156, CM5534-3PY-4PB	10496	22	30.4	18.2
	(Cal/CC-8156 x CNO'S')CNO'S'-8156, CM5534-3PY-1PB	10500	23	40.7	19.5
	"	10504	24	33.8	19.3
	"	10505	25	34.2	19.1
	"	10509	26	34.7	20.0
	"	10515	27	29.0	19.4
	"	10521	28	32.5	20.2
	(Cal/CC-8156 x CNO'S')CNO'S'-8156, CM5534-3PY-9PB	10525	29	27.8	20.1
	(Cal/CC-8156 x CNO'S')CNO'S'-8156, CM5534-3PY-11PB	10532	30	41.6	19.1
	"	10537	31	38.1	19.5
	"	10542	32	34.9	19.5
	"	10543	33	37.0	18.9

1/ Yield and grain protein data are mean values from a 2-replication nursery grown at Yuma, Arizona, USA, in 1978.

Table 29 (continued)

Permanent number	Pedigree	Seed source	Entry no.	Yield[1/] (q/ha)	Grain protein[1/] (%)
	CNO-No. 66/Wal/Bb-CNO	78Y 10551	34	43.4	17.2
	CC-INIA/CNO-7 Cerros	10556	35	38.9	19.1
	Meng//CNO'S'-No. 66	10562	36	51.0	20.0
	(CFN-CNO'S'//Jar/INIA'S'-Napo)/3/ CNO-7 Cerros, CM5461-4PY-7KB	10568	37	41.3	18.8
	Toropi/CNO-INIA'S'//CNO-INIA'S'^{2}, CM5920-1C-6-18KB	10569	38	43.5	17.1
	Saric//Cal/Tob	10578	39	37.1	18.4
	CM4483-1PY-4KB	10582	40	41.9	17.1
	CNO-7 Cerros/CNO-Pj 62//Tob-Cfn-Bb	10587	41	41.0	16.3
71836	Ciano F67/22A	10222	42	48.7	17.9
"	"	10223	43	46.6	17.8
"	"	10224	44	43.2	18.0
"	"	10228	45	40.1	18.3
"	"	11082	46	43.4	17.7
721210	NB68570/Excelsior//At166/Nap Hal	10180	47	29.3	18.5
721215	At166/Nap Hal//Dwf. Bez./Lancota	10008	48	41.4	18.2
721218	"	10015	49	39.3	17.2
"	"	10230	50	29.9	19.0
	Super X		51	48.7	14.4
	Local Check		52		
	Era		53		
721228	At166/Nap Hal//NE701152/Aurora	10609	54	31.5	19.7
"	"	10911	55	25.9	19.6
"	"	10029	56	37.3	17.8
"	"	10067	57	34.0	20.7
"	"	10073	58	33.3	22.4
"	"	10074	59	35.1	21.8
"	"	10082	60	28.7	21.1
"	"	10083	61	29.7	20.9
"	"	10084	62	31.5	21.7
"	"	10086	63	27.6	21.3
721241	At166/Nap Hal//Likafen/NE701134	11054	64	39.3	17.7
721242	At166/Nap Hal//Rousalka/NE701134	10920	65	31.0	18.6
721347	At166/Nap Hal//Norde Desprez 2	10792	66	36.1	18.0
"	"	10794	67	40.9	17.3
721351	At166/Nap Hal//Bezostaya 1	10035	68	41.7	18.7
"	"	10036	69	30.4	19.1
"	"	10617	70	28.7	19.1
721352	"	10109	71	29.3	19.2
"	"	10118	72	37.9	17.4
721355	At166/Nap Hal//Rannaya/NE701136	10121	73	31.0	18.9
"	"	10123	74	35.6	19.3
"	"	10125	75	32.2	18.2
721360	At166/Nap Hal//Centurk	10182	76	24.3	18.9
721419	Nap Hal/At166/4/Likafen/3/At166/Cmn/2/Hume	10183	77	31.4	18.1
721424	Nap Hal/At166//NB68510/Hyslop	10039	78	25.7	18.6
721425	Nap Hal/At166//NS11-35	10137	79	27.2	19.8
721428	Nap Hal/At166//Lovrin 12	10160	80	27.1	20.6

Table 29 (concluded)

Permanent number	Pedigree	Seed source	Entry no.	Yield[1/] (q/ha)	Grain protein[1/] (%)
721434	Nap Hal/At166//Sort 12-13	78Y 10200	81	20.1	19.5
"	"	10207	82	25.7	20.0
721437	Nap Hal/At166//F22-70	10215	83	27.0	20.5
"	"	10217	84	30.4	19.3
"	"	10219	85	34.2	20.3
721448	Nap Hal/At166//Aurora	10176	86	36.7	19.0
721449	Nap Hal/At166//TR535	10621	87	30.1	17.8
"	"	10828	88	37.4	17.4
"	"	10832	89	46.4	17.8
"	"	10873	90	33.5	18.3
"	"	10878	91	41.9	17.7
"	"	10945	92	31.9	18.4
"	"	10956	93	49.5	17.5
"	"	10958	94	39.2	18.4
"	"	10962	95	48.0	18.4
73619	Nap Hal/At166//Aurora	10241	96	33.4	19.7
73711	GKT-8001//Nap Hal/CI 13449	10296	97	39.1	15.7
73731	Burgas 2//Nap Hal/CI 13449	10399	98	33.4	15.9
73817	F164-71//Nap Hal/CI 13449	10365	99	38.9	17.0
73874	Nap Hal/CI 13449//Skorospelka 35	10396	100	50.1	15.8
73885	F53-70//Nap Hal/CI 13449	10383	101	44.6	17.0
"	"	10384	102	37.7	17.5
	Super X		103	48.7	14.4
	Local Check		104		
	Era		105		

Table 30.
1980

HIGH PROTEIN-HIGH LYSINE SPRING WHEAT OBSERVATION NURSERY

(95 Entries)

Permanent Number	Variety or Pedigree	1979 Yuma Source	Entry No.
	Super X		1
	Local Check		2
721218	Atlas 66/Nap Hal//Dwf. Bezostaya/Lancota	90016	3
721238	Atlas 66/Nap Hal//Skorospelka 35/NE 701137	90005	4
"	"	90007	5
"	"	90009	6
"	"	90017	7
"	"	90018	8
"	"	90019	9
"	"	90021	10
721242	Atlas 66/Nap Hal//Rousalka/NE 701134	90025	11
"	"	90028	12
721355	Atlas 66/Nap Hal//Rannaya/NE 701136	90034	13
"	"	90035	14
"	"	90036	15
721422	Nap Hal/Atlas 66//NE 701134/Aurora	90050	16
721437	Nap Hal/Atlas 66//F22-70	90053	17
"	"	90055	18
"	"	90057	19
"	"	90058	20
"	"	90060	21
721442	Nap Hal/Atlas 66//Rannaya/Lovrin 12	90040	22
"	"	90042	23
73603	Nap Hal/Atlas 66//F22-70/3/Kavkaz	90065	24
73606	Nap Hal/Atlas 66//Aurora	90067	25
"	"	90068	26
73619	"	90070	27
73627	Nap Hal/Atlas 66//Kavkaz	90071	28
"	"	90072	29
73648	Nap Hal/CR 8156//Aurora	90078	30
73649	Nap Hal/CR 8156//NB 68719	90082	31
"	"	90085	32
"	"	90086	33
"	"	90532	34
73669	Atlas 66/April Bearded/2/Greece 78310-a-3/Bezostaya 1	90090	35
"	"	90092	36
73684	Lancota/4/San Pastore/2/Hicaz/Centurk/3/Nap Hal/ CR 8156/5/NS 447	90105	37
"	"	90107	38
73688	Nap Hal/Trader/2/NS 732/3/Nap Hal/Lancer/2/Dwf. Bezostaya/ NE 701134	90114	39
"	"	90117	40
73690	F49-70/NS 974/3/Nap Hal/Lancer/2/F226-68/NB 69566	90121	41
"	"	90123	42
73697	Kitakami-Komugi/3/F226-68/Lancota/2/Nap Hal/Lancer	90127	43

Table 30 (concluded)

Permanent Number	Variety or Pedigree	1979 Yuma Source	Entry No.
73704	Dunav-1/3/NE 701136/NS 11-53/2/NB 68570/Aurora	90132	44
"	"	90134	45
"	"	90140	46
"	"	90141	47
73731	Burgas 2//Nap Hal/CI 13449	90181	48
73736	Lilifen//Nap Hal/Trader	90549	49
73786	Nap Hal/CI 13449//Burgas 2	90153	50
"	"	90155	51
"	"	90156	52
73818	F164-71//Nap Hal/CI 13449	90165	53
73875	Nap Hal/CI 13449//Skorospelka 35	90168	54
"	"	90170	55
"	"	90174	56
741231	Nap Hal/Atlas 66//CC-INIA/CNO-7 Cerros	90618	57
741233	Nap Hal/Atlas 66/3/Cal/CC-8156/2/CNO'S'-8156	90436	58
741265	Nap Hal/CI 13449//NS 12-56	90205	59
741289	Nap Hal/CI 13449//Nap Hal/CR 8156	90279	60
741293	Nap Hal/CI 13449//Tob-Turpin/No. 66	90253	61
"	"	90437	62
"	"	90597	63
741299	Nap Hal/CI 13449//MV-2	90212	64
741310	Nap Hal/CI 13449//CNO^2-INIA/Bb-Cno	90258	65
741312	Nap Hal/CI 13449//CC-INIA/CNO-7 Cerros	90282	66
"	"	90284	67
"	"	90286	68
"	"	90289	69
"	"	90454	70
741313	"	90261	71
"	"	90263	72
"	"	90264	73
"	"	90439	74
741322	Cal/CNO-Son 64//CNO'S'-Nad-Chris/3/Son 64-Kl Rend/4/ Nap Hal/Atlas 66	90267	75
"	"	90268	76
"	"	90269	77
741328	"	90265	78
"	"	90440	79
741325	CNO-Chris/HO 832/2/No. 66-Bb/3/Nap Hal/CI 13449	90612	80
741330	Nap Hal/Atlas 66/2/No. 66/Gallo	90276	81
"	"	90452	82
741338	Nap Hal/Atlas 66//NS 10-18	90222	83
741348	Nap Hal/Atlas 66//F95-71	90225	84
"	"	90433	85
741349	Nap Hal/Atlas 66//NS 10-18	90226	86
741395	Nap Hal/CI 13449//MV-2	90240	87
741426	Nap Hal/CR 8156//Talent	90247	88
"	"	90435	89
741431	Rn 12/Tob-CNO//NS 622/3/Nap Hal/Atlas 66	90446	90
"	"	90464	91
741434	Timgalen//Nap Hal/Atlas 66	90311	92
"	"	90313	93
	Super X		94
	Local Check		95

OBJECTIVE 8

Student Training

Since 1966, thirteen graduate students associated with the Nebraska wheat protein project have received Ph.D. degrees and six students received the M.Sc. degree. The students are identified together with the titles of their dissertations in Table 31. Seven of the students were from developing countries.

Ten professional people from foreign countries were associated with the Nebraska protein project on a non-degree training and study basis for periods of 6 months to 1 year. They are identified in the listing that follows:

Non-degree Training and Study

Dr. Ivan Mihaljev (Yugoslavia)	1971
Mr. P. Kishtwarz (Afghanistan)	1972-73
Dr. L. Balla (Hungary)	1973
Dr. B. H. Hong (Korea)	1974-75
Dr. Z. M. Ifzal (Pakistan)	1976
Dr. B. Borghi (Italy)	1977
Dr. N. K. Singhal (India)	1978
Mr. D. J. Maeng (Korea)	1978-79
Mr. A. A. Ahad (Afghanistan)	1978-79
Mr. M. Ivanovski (Yugoslavia)	1979-80

Table 31. Student Training.

Ph.D. Degrees:

Lay, C. L. (USA) 1972. Inheritance of grain protein content in crosses of three high-protein wheats (*Triticum aestivum* L.). Advisor: V. A. Johnson.

Stroike, J. E. (USA) 1972. Winter wheat cultivar performance in an international array of environments. Advisor: V. A. Johnson.

Ulmer, R. L. (USA) 1973. Relationships of endosperm protein fractions from normal and high protein wheats to protein content, lysine content, quality, and nitrogen fertilization. Advisor: P. J. Mattern.

Table 31 (continued)

Diehl, A. L. (USA) 1974. Inheritance of grain protein and lysine in crosses of three high-protein wheats (*Triticum aestivum* L.). Advisor: V. A. Johnson.

Vogel, K. P. (USA) 1974. Qualitative and quantitative factors affecting protein and lysine content of wheat grain. Advisor: V. A. Johnson.

Worede, M. (Ethiopia) 1974. Genetic improvement of quality and agronomic characteristics of durum wheat for Ethiopia. Advisor: V. A. Johnson.

Wilhelmi, K. D. (USA) 1976. Effect of soil nitrogen availability on nitrogen uptake and translocation in three winter wheat varieties differing in grain protein potential. Advisor: V. A. Johnson.

Kuhr, S. L. (USA) 1978. Chemical and biological determinations of protein nutritive value in selected high protein and high lysine wheats (*Triticum aestivum* L.). Advisor: V. A. Johnson.

Danakusuma, T. (Indonesia) 1978. Components of yield and adaptation in winter wheat (*Triticum aestivum* L.). Advisor: V. A. Johnson.

Worrall, W. D. (USA) 1979. Nutritional quality and cytology of wheat-like triticale revertants. Advisor: V. A. Johnson.

Da Silva, M. I. (Brazil) 1979. Effects of defoliation and N-fertilization on yield, nitrogen uptake, and protein synthesis of wheat cultivars differing in genetic potential for protein content and composition. Advisor: V. A. Johnson.

Alarcon, E. (Paraguay) 1979. Studies of general and specific combining ability in wheat (*Triticum aestivum* L.). Advisor: V. A. Johnson.

Khaleeq, B. (Afghanistan) 1980. Inheritance of grain yield, protein, and lysine in three common wheat crosses (*Triticum aestivum* L.). Advisor: V. A. Johnson.

M.S. Degrees:

Kuhr, S. L. (USA) 1974. Inheritance of protein, lysine and selected agronomic traits in four spring wheat crosses. Advisor: V. A. Johnson.

Garrison, W. E. (USA) 1978. Nutrient composition of wheat genotypes grown on international sites. Advisor: R. A. Olson.

Karathanasis, A. D. (Greece) 1978. Some soil factors influencing the yield and quality of winter wheat at international sites. Advisor: R. A. Olson.

Table 31 (concluded)

Lungu, D. M. (Zambia) 1978. Classifying winter wheat environments into adaptive zones as a basis for recommending a reduction in the number of International Winter Wheat Performance Nursery test sites. Advisor: J. W. Schmidt.

Hartmann, D. W. (USA) 1979. Genetic variation in Nap Hal, a land variety of wheat. Advisor: V. A. Johnson.

Peterson, C. J. (USA) (not yet completed) Trace mineral variation in the grain of winter wheat. Advisor: V. A. Johnson.

International Conferences

Members of the USDA-Nebraska wheat group were the principal organizers of five International Conferences. Four were wheat conferences and the fifth a conference on genetic improvement of seed proteins. These are listed in Table 32. Proceedings were published from each conference.

The Nebraska project personnel also were involved as invited participants in numerous international, national and regional conferences and seminars. The involvement of the project leaders is summarized in Table 33.

Table 32. International Conferences Organized.

1972.--First International Winter Wheat Conference. June 5-9, 1972. Ankara, Turkey. 97 participants from 24 countries. Conference Proceedings Nebr. Misc. Publ. 28. 344 pages. Editor: V. A. Johnson.

1974.--International Workshop on Genetic Improvement of Seed Proteins. Nat'l Acad. Sciences, Washington, D. C. March 18-20, 1974. 62 participants from 6 countries. Chairm. of Organizing Committee: V. A. Johnson. Conf. Proc. NAS, ISBN 0-309-02421-8. 394 pages.

1974.--Latin American Wheat Conference. October 21-28, 1974. Porto Alegre, Brazil. 149 participants from 10 countries. Conference Proceedings 446 pages. Editor: V. A. Johnson.

1975.--Second International Winter Wheat Conference. June 9-19, 1975. Zagreb, Yugoslavia. 177 participants from 35 countries. Conference Proceedings Nebr. Misc. Publ. 32. 555 pages. Editor: V. A. Johnson.

1980.--Third International Wheat Conference. May 22-June 3, 1980. Madrid, Spain. 226 participants from 40 countries. Conference Proceedings (in press). Editor: V. A. Johnson.

Table 33. Participation in regional, national and international conferences on wheat production and nutrition.

V. A. Johnson:		
	Regional	8
	National	12
	International	20
	Seminars (USA and foreign countries)	18
P. J. Mattern:		
	Regional	4
	National	6
	International	7
	Seminars	4

OBJECTIVE 9

Project Publications Summary

A large number of publications emanated from the research conducted since 1966 in the USDA-Nebraska wheat protein project. These are summarized in Table 34. The complete listing of publications and reports appears at the end of this report.

Table 34. Summary of Project Publications.

Publication category	Number
Journal articles	38
Conference proceedings	33
Nebraska research bulletins	15
Book chapters	6
Miscellaneous publications	11
Abstracts	10
TOTAL	113
Mimeographed reports	22

PUBLICATIONS

Journal Articles

1. Johnson, V. A., P. J. Mattern, and J. W. Schmidt. 1967. Nitrogen relations during spring growth in varieties of Triticum aestivum L. differing in the protein content of their grain. Crop Sci. 7:664-667.

2. Eastin, J. D., R. Morris, J. W. Schmidt, P. J. Mattern, and V. A. Johnson. 1967. Chromosomal association with gliadin proteins in the wheat variety 'Cheyenne'. Crop Sci. 7:674-676.

3. Johnson, V. A., J. W. Schmidt, and P. J. Mattern. 1968. Cereal breeding for better protein impact. Econ. Bot. 22:16-25.

4. Mattern, P. J., A. Salem, V. A. Johnson, and J. W. Schmidt. 1968. Amino acid composition of selected high protein wheats. Cereal Chem 45(5):437-444.

5. Mattern, P. J., V. A. Johnson, and J. W. Schmidt. 1970. Air classification and baking characteristics of high protein Atlas 66 X Comanche lines of hard red winter wheat. Cereal Chem. 47(3):309-316.

6. Johnson, V. A., P. J. Mattern, and J. W. Schmidt. 1970. The breeding of wheat and maize with improved nutritional value. Proc. Nut. Soc. 29(1):20-31.

7. Kies, C. and H. M. Fox. 1970. Protein nutritive value of wheat and triticale grain for humans studied at two levels of protein intake. Cereal Chem. 47:671-678.

8. Mattern, P. J., J. W. Schmidt, and V. A. Johnson. 1970. Screening for high lysine in wheat. Cereal Sci. Today 15:409-411.

9. Johnson, V. A., J. W. Schmidt, and P. J. Mattern. 1971. Registration of high protein wheat germ plasm. Crop Sci. 11: 141-142.

10. Mattern, P. J. and R. L. Ulmer. 1971. A review of lysine screening methods. Cereal Sci. Today 16:310 (paper 124).

11. Kies, C. and H. M. Fox. 1972. Interrelationships of leucine with lysine, tryptophan and niacin as they influence protein value of cereal grains for humans. Cereal Chem. 49:223-231.

12. Kies, C., H. M. Fox, and S. C. S. Chen. 1972. Effect of quantitative variation in nonspecific nitrogen supplementation of corn, wheat, rice, and milk diets for human adults. Cereal Chem. 49:26-33.

13. Kies, C. and H. M. Fox. 1970. Determination of the first limiting amino acid of wheat and triticale grains for humans. Cereal Chem. 47:615-625.

14. Kulp, K. (Am. Inst. of Baking) and P. J. Mattern. 1972. Some properties of starches derived from wheat of varied maturity. Cereal Sci. Today 17:276 (paper 85).

15. Mattern, P. J. 1972. Factors which influence the determination of wheat protein by dye-binding techniques. Cereal Sci. Today 17:284 (paper 142).

16. Banerjee, R., R. L. Ulmer, and P. J. Mattern. 1972. Nutritional quality evaluation of wheat protein using a pepsin-pancreatin digest index. Cereal Sci. Today 17:284 (paper 144).

17. 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.

18. Schmidt, J. W., V. A. Johnson, and P. J. Mattern. 1973. Registration of Belinda winter wheat germplasm. Crop Sci. 13:779.

19. Mattern, P. J. and J. B. Bishop. 1973. A cabinet with controlled humidity to bring cereal samples to constant moisture. Cereal Sci. Today 18:8-10.

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22. Klepper, Lowell A. 1975. Inhibition of nitrite reduction by photosynthetic inhibitors. Weed Sci. 23:188-190.

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30. Johnson, V. A. 1978. Protein in hard red winter wheat. The Bakers Digest (April):22-29.

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32. Pedersen, W., K. Chakrabarty, R. V. Klucas, and A. Vidaver. 1978. Nitrogen fixation (acetylene reduction) associated with roots of winter wheat and sorghum in Nebraska. J. Appl. Environ. Microbiol. 35:129-135.

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59. Stroike, J. E. and V. A. Johnson. 1976. The international winter wheqt performance nursery. Proc. 2nd International Winter Wheat Conf., Zagreb, Yugoslavia, June 1975. pp. 501-510.

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