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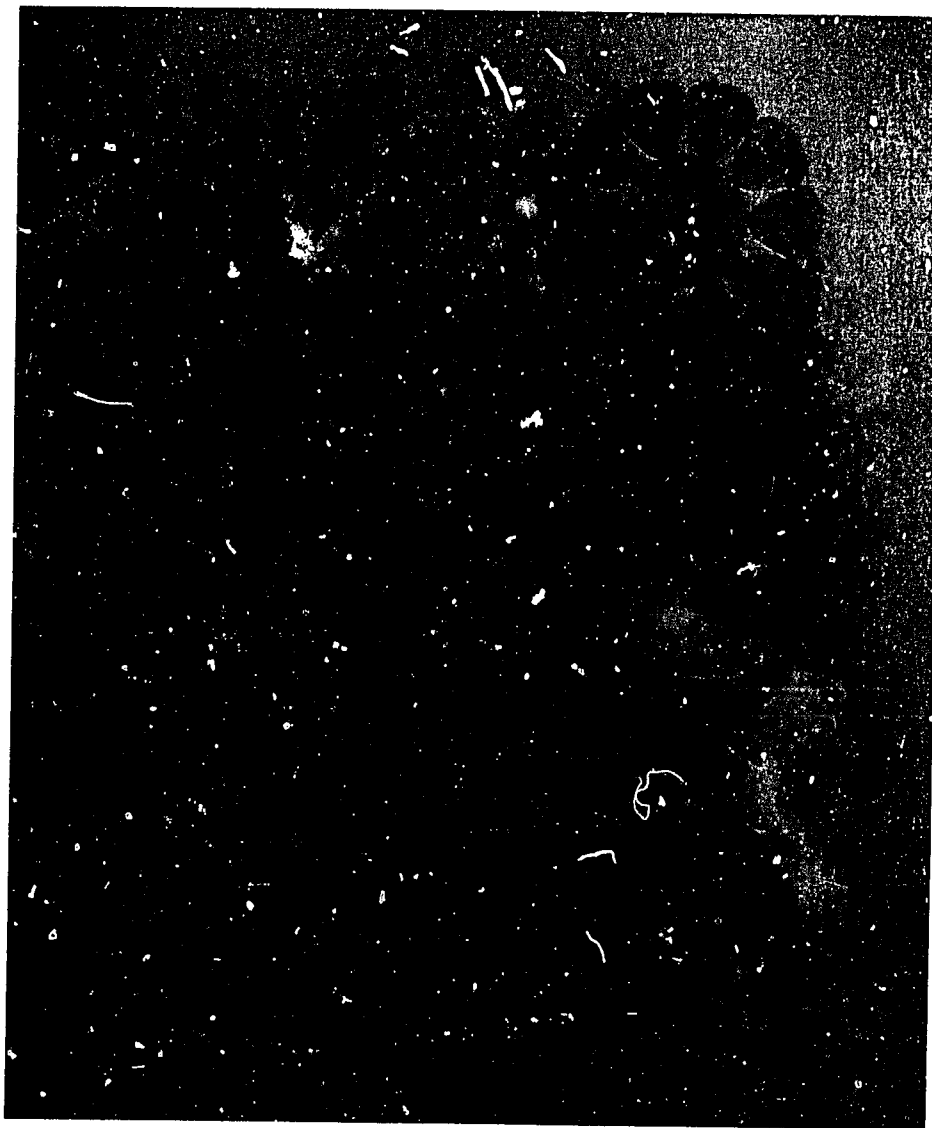
9. ABSTRACT

The year 1976 marks the end of CIMMYT's first decade and the start of the second. Recent crop reports show that developing countries have been producing 275 million metric tons of grain a year from the five major cereals, compared to 230 million tons 10 years earlier (the mid '60's). The increase in grain products was 30%, the same as the population growth in the same countries over the same 10 years. Moreover, half the increased production came from increased land area and half from increased yields per hectare. Yields of major cereals failed to keep pace with population growth; the best contribution was made by wheat (23% gain in yields). Over the decade ahead, 1976-1985 population growth in developing countries again will be 30% or a little more, and the food requirements of developing countries again will rise by 30% or more, just to maintain the present, inadequate diet. In CIMMYT's second decade, most of the increased grain production must come from increased yields on present cropland. In fact, some cropland now goes out of production and is absorbed into growing cities and towns at a rate exceeding one million hectares a year. Therefore, the effort to produce more food will confront even greater obstacles in CIMMYT's second decade. If 30% more grain is to be produced by higher yields, that can be achieved only by better technology.

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introduction

CIMMYT'S FIRST DECADE, 1966-76, AND PROSPECTS FOR THE NEXT 10 YEARS

The year 1976 marks the end of CIMMYT's first decade and the start of the second. Such a milestone justifies a look backward at what has happened to CIMMYT and its collaborators, and a look forward at the foreseeable future.

In mid-1966—about the time CIMMYT was created— demographers counted world population at 3.3 billions. Sometime in 1975 the 4 billionth person was born, very likely in a developing country where much of the population growth is occurring. CIMMYT's first decade thus coincided with a 25 percent rise in world population and a 30 percent increase in developing countries.

Population growth is expected to continue at about the same rate, at least for the next decade or two. World population will pass 5 billions in the mid-1980's and 6 billions before the mid-1990's.

These facts tell us how many people will sit down at the dinner table each night. They provide CIMMYT with its marching orders. Three cereals on which we work—wheat, maize, barley—account for 60 percent of the world's cereal production, or half the total calories and half the total protein consumed in the developing countries of Asia, Africa, and Latin America.

People/food balance

We are asked: Is cereal production expanding as fast as population? Our answer is: In one sense yes, in another sense no.

During the third quarter of the 20th century—1950-75—world wide production of cereals maintained an upward trend, per capita. That means that enough food was produced to feed additional people, and to add a little extra to the diet. On average, families in developing countries were eating a little better in 1975 than in 1950. Of course world averages mask the existence of perennial pockets of hunger, or temporary areas of distress; but the great majority of the 2 billion people in developing countries have been better off in recent years.

Now, suppose we look at cereal production in developing countries for the mid-1970's compared to the mid-1960's. Recent crop reports show that developing countries have been producing 275 million metric tons of grain a year from the five major cereals, compared to

230 million tons 10 years earlier. The increase in grain production was 30 percent, just matching the population growth in the same countries, and the same 10 years. That is on the positive side.

But there is a negative side. If we ask how developing countries achieved those gains of the last 10 years, we find half the increase came from increased land area and half from increased yields per hectare. At the end of the most recent 10-year period, developing countries were using 29 million hectares more land for cereals, compared with a decade earlier. They had transferred that land from other crops, from pasture, or from forest.

Yields of major cereals failed to keep pace with population growth. Not one of the five major cereals was able to show a 30 percent increase in yields during the decade. The best performance was contributed by wheat (23 percent gain in yields).

More than half the developing countries showed net imports of cereals at the end of the 10-year period, and the imports were larger than a decade earlier.

Over the decade ahead, 1976-85 population growth in developing countries will again be 30 percent or a little more, and the food requirements of developing countries will again rise by 30 percent or more, just to maintain the present inadequate diet.

In CIMMYT's second decade, most of the increased grain production must come from increased yields on present cropland. Very little new cropland can be opened up, and very little land can be switched from other crops. In fact, some cropland now goes out of production and is absorbed into growing cities and towns at a rate exceeding one million hectares a year. Therefore, the effort to produce more food will confront even greater obstacles in CIMMYT's second decade.

If 30 percent more grain is to be produced by higher yields, that can be achieved only by better technology at the farm level.

Performance of major cereals in developing countries.

Cereal	Area (annual)			Yield (annual)			Production (annual)		
	1961-65 (million ha)	1972-74 (million ha)	Change %	1961-65 (kg/ha)	1972-74 (kg/ha)	Change %	1961-65 (million m.t.)	1972-74 (million m.t.)	Change %
Rice	85	92	8	1626	1866	15	138	172	25
Wheat	50	62	24	973	1198	23	49	74	49
Maize	45	54	20	1136	1264	11	51	69	35
Sorghum	33	35	6	643	759	18	21	26	24
Barley	17	16	-6	937	1057	13	16	17	6
Total	230	259	13	-	-	-	275	358	30

Source: FAO Production Yearbook 1974.

Wheat and maize: two patterns

By 1975 Mexican wheats from the CIMMYT-INIA program spread across 19.3 million hectares in 15 developing countries, according to one survey. Conservatively the short wheats covered 25 million hectares in all developing countries by the mid-1970's, or 40 percent of wheat lands in the developing world. The value of the increased wheat crop could be placed at US\$2000 million per year, using a 1975 price of \$150/ton.

These are heady results achieved by 15 scientists in Mexico, plus 1000 collaborators who are doing the testing world-wide, plus the related policy makers in more than 100 developing countries.

Despite the progress of CIMMYT's first decade, there is little time for the wheat scientists to rest as we enter the next decade. Mexican wheats have been grown largely in areas of better moisture and better soils, and planted by better farmers. As often happens, profitable new technology finds its way first to areas of quickest payoff.

Looking now at the second decade, the wheat areas which have not yet benefited from the green revolution are often the areas with less favorable moisture, some with problem soils, some with difficult plant diseases, some with less skillful farmers. The wheat scientists must run faster in the second decade if they are to achieve the same increase of yields which occurred in the first 10 years.

The maize experience is different. No revolution in yields has occurred across regions. Many scientists believe there is new technology of dramatic character in the maize program. New experimental varieties are on trial in most national programs lying between latitudes 30° N and 30° S. The latest tests show a startling superiority of the experimental varieties compared with traditional varieties. This situation can be compared to 1962 in the wheat program (year of the first semi-dwarf wheat releases), and 1966 in the rice program (year IR-8 was released). A substantial leap forward is possible in the maize program.

The network of maize scientists in the mid-1970's is more experienced than was the wheat network of 1962. The maize network can serve as a pipeline for the rapid delivery of this new technology to the research stations of developing countries, and from there it will pass to agencies which deal with farmers.

1976-86

CIMMYT enters its second decade with a number of strengths. Our authorized international staff numbers 58 in 1976, compared with eight in 1966.

Our total financial resources in 1976 exceed US\$13.7 million compared to less than \$1 million 10 years ago.

Our access to eight fine research stations in Mexico offer better facilities than a few years back.

There are other favorable indicators which are less visible. More governments are giving first priority to agriculture. More governments are making policy decisions which directly support the introduction of new technology (such as price supports, fertilizer supplies, grain storage facilities).

Scientists employed by national programs are expanding in both numbers and skills. This should continue.

Industrialized countries have assigned more of their sophisticated research facilities to work on the problems of agriculture in developing countries.

Overall, this is a machine of many parts, and the world is still learning how to make the parts run harmoniously, while preserving a sense of initiative at every level, which alone can maintain high motivation.

It is both cliché and fact that the two most pressing problems of the quarter century ahead are population and food. And the crop scientists find themselves at the interface, swept forward by the sense of urgency.

Haldore Hanson
El Batán

maize improvement



INTRODUCTION

Maize ranks third among world food grains, after wheat and rice. The importance of maize can be measured by the area planted (110 million hectares in the world) and by the size of harvest (300 million tons).

Maize in developing countries

Half the maize area of the world is planted in developing countries of Asia, Africa, and Latin America. But only one quarter of the world crop is harvested there. This contradiction is caused by low yields. Whereas industrialized countries of Europe and North America harvest an average of 4600 kg/ha, the developing countries average only 1200 kg/ha.

The low yields in developing countries offer wide opportunity for maize improvement. Improvement could benefit at least 500 million people who eat maize as their staple diet, either all the year around or during one cropping season when other basic foods are not available. Moreover, poultry and swine are the chief source of animal protein in maize-eating countries, and improved maize production will go partly into animal products, thus further improving the diet.

Constraints in production

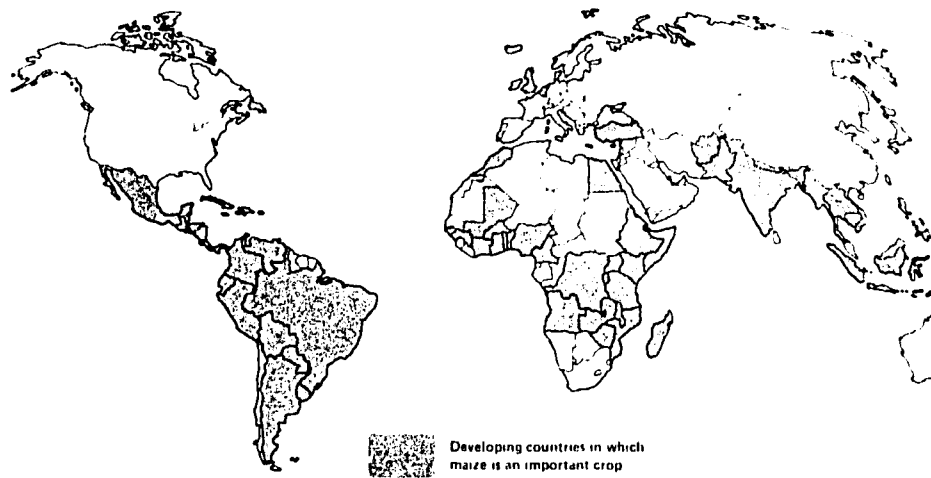
Historically, improvement of maize in these developing regions has faced a number of constraints.

First, wide adaptation was needed. When Columbus found maize growing in the Western Hemisphere 500 years ago, ancient travellers had already carried maize from its place of origin in the lowlands of Middle America to the highest slopes of the Andes in South America and to the temperate regions of North America. Maize had proved itself more widely adapted to different climates than the other food grains. The potential for wide adaptation is still there.

However, scientific research on maize improvement during 1800 to 1950 was concentrated largely in Western Europe and North

Area and production of maize in four regions, 1973.

Region	Area (million ha.)	Production (million metric tons)
Latin America	27.9	38.9
Far East	14.6	14.7
Africa	11.9	13.2
Near East	1.9	4.6
Total	56.3	71.4



America. Higher yielding materials, with narrow adaptation, were developed for each temperate-zone country and locality. By World War II it was exceedingly difficult to move these improved maize materials back to their tropical homeland. Clearly, improved materials are needed for the tropics and these new varieties must have wider adaptation.

Another constraint was plant height. In the tropics, traditional maize grows 4 to 5 meters high and often lodges (falls over) before harvest. Improved maize in the temperate zone is only about 2 meters high. So a shorter tropical plant was needed.

A third constraint was pests. Diseases and insects are more numerous and severe in the tropics. Genetic resistance to diseases and insects was needed, and the research had to take place in the hotter regions, not in the temperate zone.

A fourth constraint lay in the poor quality of maize protein. Maize contains 9 to 11 percent total protein, but only half can be utilized by humans because maize protein is deficient in two essential amino acids, lysine and tryptophan. When maize is eaten as the principal food, it does not provide a satisfactory diet unless the two deficient amino acids are supplemented from other foods in the diet. Such diversity of diet is often lacking, especially among low-income populations in much of the developing world.

A fifth constraint was hidden within the enzymes of the tropical maize plant: it is "less efficient." This means that for every ton of dry matter (stalks, leaves, ears, tassel), the tropical plant puts less dry matter into grain than improved temperate-zone maizes, and more into fodder which humans cannot eat.



At the Poza Rica experiment station, Gonzalo Granados explains the operations of the back-up pools.

Finally, improvement of maize production requires a trained and efficient work force of scientists distributed among the 55 developing countries where maize is a basic food. An international center like CIMMYT can serve as a "mixing plant" for new varieties of maize, but the testing and selection of improved maize must take place in each climatic zone where the crop is grown. Hence governments of producing countries must share the task, and more scientists are needed.

In short, the constraints for improving maize in developing countries are numerous: varieties are needed that are more stable in yield, with wider adaptation, shorter stature, shorter growing period, greater resistance to insect and diseases, better quality protein, and more efficient grain production. Putting all these steps together is a major task requiring more trained scientists in developing countries.

Short program history

Maize improvement in Mexico had its beginnings in the 1940's as a government program in cooperation with the Rockefeller Foundation. The purpose was to increase food production quickly, with limited resources and personnel.

Hybrids were developed first because they offered a potential yield increase of about 25 percent over traditional varieties in the best producing areas. Early Mexican hybrids were outstanding in production, some comparing favorably with the top yields in North America. But they did not spread in Mexico. Hybrids never covered more than 10 to 15 percent of Mexican maize lands.

Why? The obstacles slowly became apparent?

- Producing an adequate supply of hybrid seed for 8 million hectares of Mexican maize land requires rare scientific management. In most advanced countries this task is performed by private companies. Many developing countries have tried to produce hybrid seed through government agencies, and not one has equalled the success of Western Europe or North America.
- Distributing seed to tens of thousands of villages is a vast marketing job.
- Farmers who traditionally saved seed from one crop to the next were reluctant to pay premium prices for new hybrid seeds each year.
- Hybrids gave little added yield unless there was ample moisture and fertility. Yet most maize in Mexico was grown by smallholders under rainfed conditions, without fertilizer.

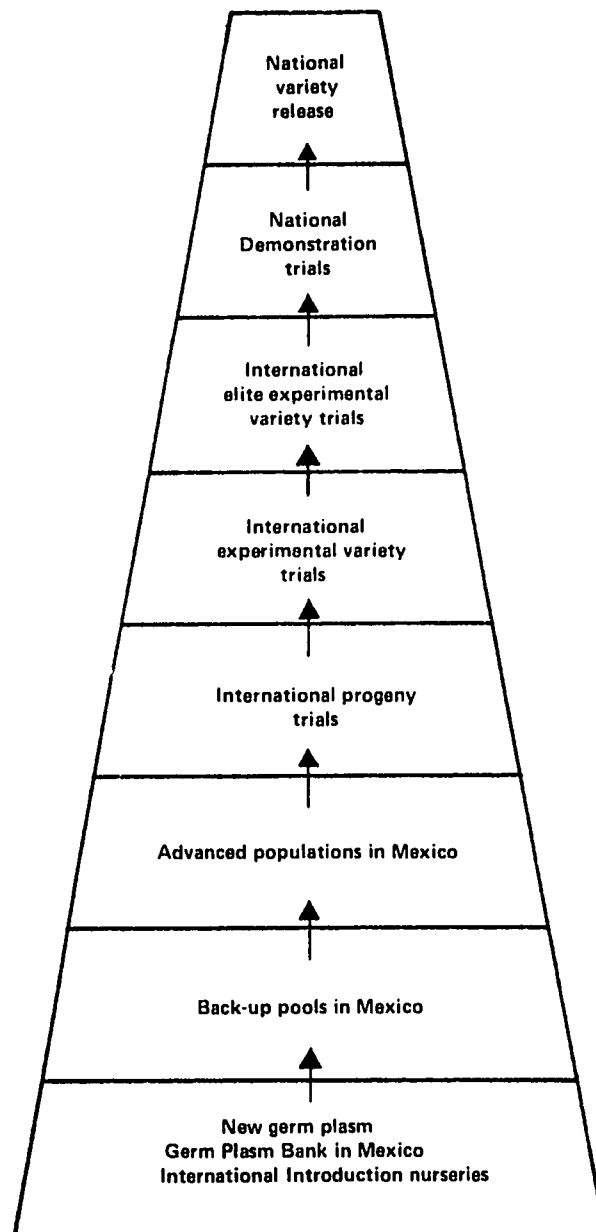
In other words the whole production package was not adopted by the farmers. Similar experiences can now be reported in many developing countries of Asia, Africa, and Latin America.

Consequently, in the last half of the 1950's, scientists in Mexico began putting together genetically diverse maize populations, or composites, to supplement the hybrid program. They aimed for long-range population improvement and the release of open-pollinated varieties that would have yields about the same as hybrids. With such varieties, seed can be saved from one crop to the next, and passed from farmer to farmer at considerable savings, without the great drop in yield which occurs when seed from hybrids is replanted a second generation.

One of the earliest improved populations in Mexico was a mixture from the race Tuxpeño. Five kilograms of its seed was sent to Honduras in 1961 and that variety now covers the bulk of the Honduran maize land.

At the beginning of the 1970's many populations were undergoing improvement in the CIMMYT program, some of them excellent, but

The Maize Pyramid



National variety release

Based on world-wide data and farmer reactions to local demonstrations, each national program decides whether to release and recommend the new variety

National demonstration trials

National programs alone decide whether an elite experimental variety justifies wider demonstrations on farmers' fields. CIMMYT can supply up to 49 kg of seed, and each government further increases the seed. In larger countries, demonstration trials take place at thousands of sites.

Elite experimental variety trials

Again drawing upon reserve seed, CIMMYT in Mexico ships enough sets for trials to about 125 sites the following summer season. For the first time, some trials are held on private farmers' fields.

International experimental variety trials

In Mexico during winter season, CIMMYT staff inter-cross the 10 best progeny from each site using reserve seed and the random mating method, to produce an experimental variety which will be tested by collaborators at 20-25 sites, world-wide, during the following summer season. Data from these 20-25 sites determine the following year's elite experimental varieties.

International progeny trials

The 250 progenies from each population are sent to collaborators at five sites, world-wide, to be grown in 250 5-meter rows, with six local checks, forming a 16 x 16 lattice. Ten best progeny are identified by the collaborator at each site, to form one experimental variety for the following year.

Advanced populations in Mexico

Here materials continue to be grouped by agro-climates, but unlike the pools, the populations have completed generations of selection for better plant type, better disease and insect resistance, better yield. These populations are grown in Mexico, and 250 superior families (progeny) are selected from each population for international testing once a year.

Back-up Pools in Mexico

Here germ plasm is classified into 34 pools (genetic soups) according to agro-climatic characteristics, grain types, and length of growing season. There are 12 pools for the lowland tropics, 14 pools for the highland tropics, 8 pools for the temperate zone. Back-up pools are grown twice a year in Mexico, using half-sib (half sister) selection method, and seed from a few superior families moves up annually to advanced populations.

New germ plasm

The Germ Plasm Bank in Mexico contains 12,000 accessions (varieties, lines, wild types) which are continuously being classified for economic characteristics.

International introduction nurseries consist of improved materials from other countries, newly arrived in Mexico.

Each year the best new materials are added to the Back-up pools.

most were still heterogeneous in economic characters, and not sufficiently stable for farmer use. Not until 1970 did CIMMYT acquire its tropical base at Poza Rica, Veracruz, and the stage was set for rapid progress.

CIMMYT spent several more years (1970-73) improving these populations, then took several decisive steps leading to the present maize program:

- Populations which had been improved were classified by major agro-climatic regions and grain type, to meet the requirements of farmers in the various producing regions. Wherever a gap was found (a maize environment not yet served), the formation of a new population was begun.
- Widespread testing began for CIMMYT's best germ plasm starting with the range of climates in Mexico (sea level to 2600 meters), then in the major producing regions of the world.
- To make certain that superior new germ plasm was entering these trials, 34 pools of germ plasm were organized in Mexico to feed tested and classified materials into the advance populations.
- Finally, CIMMYT's maize staff was reorganized into groups which were relabelled "advanced unit" and "back-up unit", to give adequate attention to each of these steps.

The rest of this story on program evolution concerns the results of international testing during 1973-75, a process which will reach a climax in 1976, with the testing of the first elite experimental varieties at more than 100 sites around the world.

Procedures for new varieties

The process for developing experimental varieties will be treated here only briefly.

CIMMYT selection for better maize can be compared to the steps which a government uses when it selects its national football (soccer) team for international competition.

First come the tryouts for unknown and untrained players. They are tested against each other. A few are truly superior and are sent to training camps where they mingle with more advanced players, under the eye of the coaches.

Next, the pool of players is subjected to regional and national competitions, and exhibition matches with other national teams. After each test some players are dropped and others promoted.

Finally the international test matches begin, and after many contests, the greatest team becomes champion.

By similar process, CIMMYT begins its tests with raw germ plasm from the world seed bank, and with tests for improved materials newly arrived in Mexico from national programs. A few survive these

Agro-climatic characteristics considered in classifying maize gene pools.

Maturity range	Altitude meters	Latitude	Temperature (Mean of main growing season)	Days to silking	Duration of crop growth days
<i>Tropical-Subtropical lowland</i>					
early	0-1600	0-30° N-S	25-28°C	Up to 50	90-100
medium	0-1600	0-30° N-S	25-28°C	50-60	100-110
late	0-1600	0-30° N-S	25-28°C	60 +	110-120
<i>Tropical highland</i>					
early	1600 +	0-30° N-S	15-17°C	Up to 70	Less than 130
medium	1600 +	0-30° N-S	15-17°C	70-95	130-190
late	1600 +	0-30° N-S	15-17°C	95-120	190-240
<i>Temperate</i>					
early	0-1600	30-40° N-S	20-22°C	Up to 60	100-120
medium	0-1600	30-40° N-S	20-22°C	60-75	120-150
late	0-1600	30-40° N-S	20-22°C	75 +	150 +

tests and are promoted to the back-up pools.

Next come more trials and more elimination, each with stricter criteria, until a stage arrives at which the 10 best families (progeny) have been identified in one advanced population, through international competition. This stage is comparable to the naming of one national football team.

The 10 progeny are intercrossed by CIMMYT staff to make one homogeneous experimental variety, and this variety is tested against 100 to 150 other experimental varieties, first at 20 to 25 locations in the world, then at 100 to 125 locations. The materials which survive this final elimination contest are comparable to international champions. Governments are free to release the champion materials to farmers.

Graphically, the CIMMYT elimination process can be shown in the form of pyramid of eight steps leading to the best elite experimental varieties. The pyramid process is repeated every year as a continuous flow, and experimental varieties emerge from the top of the pyramid in annual procession. At present, the advanced populations may generate as many as 150 experimental varieties a year. These will be reduced to no more than a dozen elite experimental varieties for the following year. Different governments may release each of the elite varieties, to farmers depending upon their performance in competition with local varieties.

Over time, progress at CIMMYT can be measured by each year's elite varieties compared to those of previous years. Every year the elite varieties should be better than their predecessors in disease and insect resistance, range of maturity, and yield.

1975 INTERNATIONAL TESTING

In March-April 1975 CIMMYT air shipped 174 experimental variety trials to collaborators in 41 countries. At the same time, seed went out from Mexico for progeny trials at 138 sites in 21 countries. By December 15, 1975 (cutoff date for publication of preliminary results), CIMMYT had received data from one-third of the experimental variety trials; and almost half the collaborators in the 1975 progeny trials had either sent in data or cabled their selections of the 10 best progeny. These selections are used to form experimental varieties for 1976.

CIMMYT was able to publish the preliminary results of the 1975 trials within the year in which the trials were grown. This permits both the national programs and CIMMYT to plan their 1976 testing from the preliminary results of 1975.

The final report for 1975 will appear in mid-1976 and will include

International maize trials 1975 and 1974.

Region and nation	1975 Progeny trials	1975 Exp. Var. trials	1974 Progeny trials	1974 Exp. Var. trials
<i>Latin America & Caribbean</i>	<i>72</i>	<i>109</i>	<i>90</i>	<i>37</i>
Barbados	0	0	0	2
Belize	0	1	0	1
Costa Rica	4	4	2	2
Dominican Republic	0	4	2	0
El Salvador	4	7	2	1
Guatemala	7	6	6	1
Haiti	0	4	0	1
Honduras	5	4	5	2
Jamaica	0	4	0	1
Mexico	39	24	50	6
Nicaragua	4	4	3	1
Panama	3	4	3	3
Argentina	0	2	0	1
Bolivia	0	14	0	2
Brazil	0	6	0	5
Chile	0	1	0	0
Colombia	2	9	14	4
Ecuador	4	4	3	2
Peru	5	5	0	2
Venezuela	5	2	0	0
<i>Tropical Africa</i>	<i>20</i>	<i>29</i>	<i>11</i>	<i>26</i>
Cape verde	0	0	0	1
Ethiopia	0	1	0	1
Ghana	0	3	0	2
Ivory Coast	5	4	0	1
Kenya	0	4	1	2

continued

late-arriving data; results in the final report are not expected to alter the preliminary findings, but should augment the analysis.

Speedup of the report was made possible by many factors:

- Air express shipments of seed reached most collaborators before their normal planting date.
- CIMMYT staff visited most collaborators during the trials and helped "read" the experimental crops.
- Collaborators cabled their observation data to Mexico.
- CIMMYT pre-programmed the trials on computer, and inserted the data as it arrived.
- The preliminary report was issued 2 weeks after the closing date.

Some further speedup of international trials may be possible in 1976, but there will normally be slippage affecting perhaps 50 percent of the trials caused by difference of planting dates in different climatic zones, by abnormal local weather (drought, flood, frost), and occasional

International maize trials, continued.

Region and nation	1975	1975 Exp.	1974	1974 Exp.
	Progeny trials	Var. trials	Progeny trials	Var. trials
Malawi	0	0	0	10
Mozambique	0	3	0	0
Nigeria	6	3	5	3
Tanzania	9	6	5	3
Zaire	0	4	0	2
Zambia	0	0	0	1
Central African Republic	0	1	0	0
<i>Mediterranean/Mideast</i>	<i>9</i>	<i>10</i>	<i>8</i>	<i>5</i>
Egypt	5	4	5	2
Iran	1	2	0	3
Turkey	3	2	3	0
Yemen Arab Republic	0	1	0	0
Algeria	0	1	0	0
<i>Asia</i>	<i>27</i>	<i>26</i>	<i>44</i>	<i>16</i>
Bangladesh	0	2	0	0
India	12	5	17	5
Indonesia	0	1	2	0
Khmer	0	1	0	0
Malaysia	0	0	0	1
Nepal	0	7	7	3
Pakistan	6	4	11	2
Philippines	5	3	3	1
Thailand	4	3	4	4
<i>Other</i>	<i>0</i>	<i>0</i>	<i>1</i>	<i>0</i>
USA	0	0	1	0
Total	138	174	154	84

failures of air delivery. Trials which produce delayed results are still of great value, because they enable each collaborator to relate his local observations to the world data.

**Experimental
variety
trials**

The 1975 experimental variety trials showed some remarkable results. For example:

- Out of 53 experimental variety trials reported to the end of 1975, 30 trials contained experimental varieties which outyielded all local checks (usually best local varieties). The experimental varieties also equalled or bettered the checks in all agronomic aspects. The table shows some examples.
- Results of the trials lend support to the strategy that experimental varieties developed from progeny selected in one part of the world can give outstanding performance in other parts of the world. Hence, international collaboration should accelerate the development of better varieties with wider adaptation.
- Based on the 1975 experimental variety trials, nine nations requested CIMMYT to develop elite experimental varieties for their use in 1976. Part of each elite trial will be grown on private farmers' land. Normally, testing on private lands is a step preparatory to release of a new variety.
- About a dozen nations have reorganized their national maize programs to follow the pattern of trials which CIMMYT is now using, including the development of experimental varieties. This

Some results of International Experimental Variety Trials 1975.

Testing site	Trial no.	Experimental Variety		Yield, kg/ha	Best check yield kg/ha	Increase of experimental variety over best check, %
		Name	Selected in			
Nepal, Rampur	11	Amarillo dentado	Mexico	4100	3700	8
Ivory Coast, Ferkessadougou	12	Maquina 7422	Guatemala	8700	6200	41
Panama, Ceiat	13	Tocumen 7428	Panama	8100	6900	18
India, New Delhi	13	Yusafwala 7428	Pakistan	4200	1900	117
Costa Rica, Guanacaste	14	Yusafwala 7435	Pakistan	4000	1600	151
Guatemala, Cuyuta	14	Yusafwala 7435	Pakistan	1700	1100	54
Turkey, Samsun	16	Pirsabak 7448	Pakistan	7700	6900	11
Nepal, Khumaltar	16	Pirsabak 7446	Pakistan	5700	4500	25

has occurred in Zaire, India, Pakistan, Nepal, Thailand, Egypt, Tanzania, and six countries of the Central American region.

This change of procedures at the national level makes it easier for comparisons to be made with international materials. And ultimately, as stronger national programs develop their own experimental varieties, it is safe to forecast that national varieties will flow into the internation-

Frequent discussion among members of the maize staff is an integral part of the maize improvement process. From left, John Vessey, Gonzalo Granados, Surinder Vasal, and Ernest Sprague.





Mario Martinez of the Mexican extension service describes an on-farm trial conducted collaboratively with CIMMYT.

al testing program, and some will be better than those produced at CIMMYT.

Competition will benefit all collaborators.

**International
progeny
trials**

Reports received from collaborators who grew 138 progeny trials in 1975 were exceedingly favorable. Each collaborator received 250 progeny from an advanced population, which he tested against the best local varieties (checks), and from the results, he chose the 10 best progeny. Each set of 10 best is being inter-crossed by CIMMYT in Mexico during the winter season of 1975-76, to create experimental varieties for 1976.

Certain of the 1976 experimental varieties should again be outstanding, if they live up to the performance of the 10 progeny from which each is created.

For example, 80 percent of the collaborators who grew the progeny trials in 1975 found the mean yields of the 10 best progenies to

be significantly better than the best checks. The superiority in yield was within 10 to 20 percent at most sites. This gain in yield should be reflected in the 1976 experimental varieties.

Moreover the 10 best progeny had shorter plant height, compared to the best checks, at 90 percent of the test sites. The best progenies were shorter by 10 to 80 centimeters at most sites. Days of growth from planting to silking were about equal between the best progenies and the best checks. The best progenies generally had less lodging, less ear rot, and less leaf disease, compared with the best check.

Each of these superior traits should be retained in the 1976 experimental varieties.

FLOW OF NEW GERM PLASM

Each year some new germ plasm of superior quality is added to the advanced populations. The back-up unit is responsible for the selection process. Highlights of the back-up operation in 1975 are reported here.

Flow from the bank	About 40 accessions in the germ plasm bank having characters especially needed in the back-up pools were crossed with materials in the pools during 1975; progeny will be observed before the best are incorporated into the pools. This process will be repeated each year.
Introduction nurseries	Hundreds of materials newly arrived in Mexico from national programs were planted in observation nurseries in Mexico during 1975 and the best 5 to 10 percent were moved directly into the back-up pools. New materials are especially needed for earliness and disease-insect resistance.
Flow to advanced populations	Four out of 14 tropical back-up pools were tested in 1975. From each population 250 superior families were selected, and yield tested at three locations in Mexico. The best families will be used to generate new advanced populations. In 1976 this process will be repeated with three temperate pools, which will be tested both in Mexico and at ICRISAT in India. The 50 to 100 best families across sites will be used to generate new advanced populations for temperate regions.
Early pools	Tropical pools for early maturity have not proved early enough to meet the needs of CIMMYT's breeders. To upgrade the germ plasm, these pools were crossed in 1975 with a mixture of families from advanced populations, having earliness and matching grain type. The best early progeny from these crosses will be selected from the F_2 's in 1976 and used to reconstitute the tropical early pools.

Highland pools	Advanced populations of highland types which will be formed in 1976. The best 250 families from five of the highland pools were selected in 1975 and will be yield tested in 1976 at two highland locations in Mexico, one in South America and one in Africa.
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GERM PLASM BANK

A germ plasm bank is a service unit for researchers. The bank unit collects and stores seed, regenerates seed, tests and catalogs seed, and ships seed to users.

Collection and storage	The 12 000 items in the CIMMYT bank were gathered mainly by an agency of the Mexican Ministry of Agriculture during the late 1940's, and early 1950's under a project financed by the Rockefeller Foundation. Over 90 percent of the collection consists of the species <i>Zea mays</i> L. the collection also contains near relatives including <i>Zea mexicana</i> , <i>Zea perennis</i> , and garden in which CIMMYT maintains most of the species of <i>Tripsacum</i> (a relative of maize).
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The bank is held in concrete chambers at a temperature of 0°C. There are over 18,000 labelled storage tins of 2-liter and 4-liter capacity containing 39.5 tons of seed. The tins are arranged on steel shelving like library stacks.

An inventory of the collection has been recorded on a computer so that the name of each entry, its species, country of origin, current quantity of seed and the location of its storage tin, can be found easily.

A duplicate seed supply for the CIMMYT collection (500 grams per item) is being deposited for long term storage at the U.S. Seed Storage Laboratory in Fort Collins, Colorado, U.S.A.

Regeneration	Fresh seed was grown for over 8000 bank items between 1969 and 1975. Over 90 percent of the bank now consists of seed less than 7 years old. About 600 items must be increased because their seed supply has dropped below 500 grams.
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Classification and cataloging	Over 8000 of the bank items have been documented for agronomic characteristics, and 3000 of them tested in replicated yield trials. These data are being assembled in a catalog to be published in 1976. In preparing the catalog, CIMMYT collaborated with the U.S. National Seed Storage Laboratory and the International Board for Plant Genetic Resources.
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Shipments to clients CIMMYT offers free samples of seed from the bank to all research organizations. From 1966 to 1975 the bank made 588 shipments to 80 countries, representing almost 25,000 seed items. During 1975 alone there were 71 shipments totalling 5250 seed items.

A large backlog of maintenance work and classification for the bank was completed during between 1970 and 1975, and in future years, CIMMYT expects to fulfill its role as caretaker of the world's largest maize collection.

SPECIAL RESEARCH PROJECTS IN MEXICO

When CIMMYT identifies problems or weaknesses in the genetic material that might be corrected genetically it establishes a special project. As an example the height of all CIMMYT tropical maize material has been greatly reduced, but just how short tropical maize could be or what the optimum height of tropical maize should be is not clear. Therefore, a special project was started in one population to select for reduced height to provide an answer to these two questions. The conclusions will then be applied to the total program. Also, the product of this study may serve as a parent to change height in other materials more rapidly.

At present CIMMYT is working on four special projects for shorter plant height, shorter maturity (days of growth from seeding to maturity), wider adaptation, and greater plant efficiency for the tropics.

Reduced plant height Over 12 generations since 1968 CIMMYT has shortened some varieties of tropical maize by 1.0 to 1.5 meters, to the approximate height of "corn belt" maize. Now a special project has been created to determine how far the shortening process can proceed without adversely affecting yield.

So far, reduced plant height has reduced lodging, and the shorter plant has been found to tolerate denser plant population. These two factors have added an extra 2000 kilograms of grain per hectare.

Shorter maturity Some of the best tropical maize populations in Mexico are slow to mature and fail to fit into the cropping rotations of other maize growing regions of the world (for example, a rotation of rice-rice-maize within 12 months in Southeast Asia). This problem is approached by pooling available short-season materials, intercrossing them, and selecting for earlier maturity in agronomically desirable plant types.

The growing period of some advanced populations in Mexico has

been shortened by 7 days between seeding and flowering. Selection for still shorter maturities continues.

**Wider
Adaptation**

Eight years ago a CIMMYT breeder began crossing maize materials from widely differing climates (for example, Western Hemisphere varieties from Northern Canada, the equator, and southern Argentina). Because of diseases and daylength sensitivity, cold climate varieties initially would not set seed in the lowland tropics and vice versa.



From among thousands of ears, only a few will be chosen to be planted in the next crop season.

Now, after eight cycles of intercrossing, the mixture is satisfactorily setting seed in all climates.

The best progeny from this material can now be used as donor parents to transmit wider adaptation to advanced populations. It can also be used as a vehicle for transferring new genes to nearly any place in the world.

**More efficient
tropical plants**

CIMMYT researchers have discovered that tropical maize produces about as much dry matter as the temperate corn belt plant. The difference in grain yield is caused not by heat and humidity or low light intensity, but by inefficiency of the plant (it devotes more energy to fodder and less to grain).

CIMMYT is selecting for a change in three characteristics which distinguish the tropical plant: tall stature, large tassel, and greater foliage above the ear. In other words, CIMMYT is selecting to alter the tropical maize plant to be more like the temperate plant in the hope that this will make the tropical maize plant more efficient.

CIMMYT shortened the tropical plant but this alone did not increase the efficiency of the individual plant (although the ability of the shorter plant to tolerate higher density of planting has added potential yield per hectare).

Now CIMMYT has created a special project to reduce tassel size and reduce the foliage above the ear. Within a few years a modified plant should provide the answer whether less fodder production means more edible grain.

CIMMYT believes each special project should provide usable tools for maize research within a reasonable time, or be modified, or dropped.

PROTEIN IMPROVEMENT

Protein is unsatisfactory in most maize. In a commercial maize crop, protein ranges from 9 to 11 percent of the grain weight, which is adequate for balanced human nutrition if all of it could be utilized. But maize protein is low in lysine and tryptophan, two essential amino acids. Because of inadequate lysine and tryptophan the body can utilize only half the protein in normal maize. Lysine is typically 2 percent of protein in normal maize, whereas 4 percent would be needed to permit use of all the protein.

Scientists at CIMMYT and elsewhere have been working for a decade on the problem of poor quality maize protein.

Maize protein can be improved by introducing various genes, but

the added genes bring undesirable effects which have not yet been fully resolved.

One breeding approach is through opaque-2 mutant gene (the name comes from the appearance of the kernel), but opaque-2 maize has serious defects: yield drops because the opaque-2 maize contains a soft endosperm which weighs less than the endosperm of normal maize; most consumers of maize are reluctant to accept opaque-2 maize as a food because of its appearance; adequate disease and insect resistance has not been obtained in the newer quality protein maize.

Since 1969 CIMMYT breeders have been selecting opaque-2 populations with modified hard endosperm, normal appearance, resistance to ear rots, and higher tolerance for stored grain insects. This is a slow process.

Continued steady progress was indicated by international maize trials in 1975 which confirm the following status:

(1) CIMMYT now has at least one opaque back-up pool or opaque advanced population which equals or surpasses in yield the best normal maize checks in each major climatic zone (lowland tropics, highland tropics, temperate zone).

(2) When 23 experimental varieties carrying opaque-2 gene were tested world-wide in 1975, their yield averaged 101 percent of the best normal check (without the opaque-2 gene).

Breeders estimate that correction of the susceptibility to ear rots will add another 5 to 10 percent to yields.

CIMMYT has entered into collaborative research with the national programs in Philippines, Nepal, Zaire, Tanzania, Ghana, Ecuador, and Guatemala. Each is committed to the development of open-pollinated opaque varieties suitable for its own agro-climates.

**Floury maize
conversion**

In highland locations, particularly in the Andean region, farmers prefer maizes that have soft endosperm and large kernels. These are called floury maize. In 1975 CIMMYT crossed 21 floury maizes with sources of the opaque-2 gene. Since the floury kernels have the same opaque appearance as opaque-2 kernels, the ninhydrin test (chemical laboratory test) is used to select segregating kernels that contain the opaque-2 mutant gene.

A composite was formed from opaque-2 x floury-1 crosses that were made in 1974. Selected ears from this composite were shelled and the largest kernels from each ear were planted in 1975 to obtain a second cycle of recombination. Several more cycles will be needed to judge progress.

**Sugary-2
conversion**

Scientists at Purdue University (USA) have found that the double mutant sugary-2 x opaque-2 has several advantages over ordinary

opaque-2 maize; for example, hard endosperm, good digestibility, good biological value, less ear rots, and less damage from storage insects. One disadvantage is the small size of the kernels which causes lower yield.

Crosses have been made and some segregates reached the F₂ generation in 1975. This breeding approach is still at an early stage.

Protein outlook Little maize has been planted commercially with high quality protein. U.S.A., Brazil, and Colombia have released opaque-2 hybrids which are grown mainly for animal feeds. In the U.S.A. less than 200,000 hectares of opaque-2 maize is grown.

CIMMYT believes that a breakthrough on commercial use of high quality protein maize will come only when a variety carrying the opaque-2 gene, or its equivalent, shows yields and agronomic performance equalling or surpassing the existing normal varieties, and the protein quality is a bonus.

DISEASE AND INSECT RESISTANCE

The plant protection staff (pathology and entomology) work as part of the inter-disciplinary maize team.

Companion nurseries To determine how each family of maize reacts to high levels of disease and insect attack, the CIMMYT staff plants along side each trial of advanced populations, a "companion nursery" which is subjected to severe attacks by diseases and insects. The procedure is as follows: One half of each row in a companion nursery is exposed to natural insect infestations and the other half of the row is inoculated with spores of pathogens for the most destructive diseases of maize in Mexico. CIMMYT staff scores each row for insect damage and for disease reaction. Rows which show the greatest tolerance for diseases and insects are retained for succeeding generations. Under selection pressure, the maize populations should gradually increase in resistance to common diseases and insects.

Insect rearing laboratory Millions of insect eggs are required for deliberately infesting the companion nurseries. An insect-rearing laboratory has been developed which has the potential to produce 500,000 egg masses a year, from four insect species, sufficient to infest all the maize progenies at CIMMYT stations. The species are (1) fall army worm (*Spodoptera frugiperda*) (2) maize ear worm (*Heliothis zea*) (3) the sugarcane borer, (*Diatraea saccharalis*) and (4) the neo-tropical borer (*Zea diatraea lineolata*). These are the most widespread pests affecting maize in México and the tropics of the Western Hemisphere.

In 1975 CIMMYT inaugurated a new building for insect rearing, which was built and equipped at a cost of US\$100,000. It contains 12 chambers with controlled temperature and moisture permitting egg masses to emerge at the right time for infesting each maize experiment.

Collaborative research Three damaging diseases of maize and several insect pests of maize, none of them prevalent in Mexico, are found in large areas of the world. The exotic diseases are downy mildew (*Sclerospora* spp), a fungus disease found mainly in Asia from Indonesia to India, and rapidly spreading to other continents, maize streak virus, disseminated by a leafhopper (*Cicadulina* spp) found in tropical Africa, and corn stunt disseminated by a leafhopper (*Dasibulus* spp) in tropical Latin American countries.

In addition, exotic insects are the different species of African maize borer complex and the Asian maize borer complex.

To identify maize with genetic resistance to these diseases and insects, CIMMYT has entered into collaborative research with strong national programs in areas where these problems are most intense.

For example, in 1975 CIMMYT sent seed for 4000 experimental lines of maize to six locations in the world. Two sets went to Thailand and the Philippines to be tested for downy mildew; two sets to Nigeria and Tanzania, to be tested for resistance to maize streak; two sets went to Nicaragua and El Salvador, to be tested for resistance to stunt. The superior lines are returned to CIMMYT where they are recombined and new progeny generated for the same test in the next year.

CIMMYT expects to achieve strong resistance to the three diseases and to combine the resistance into the improved populations of maize for the tropics.

Insects in stored grain A scientist from the Tropical Stored Products Institute in U.K. spent 2 years at CIMMYT 1974-75, studying insects which attack stored maize.

One set of studies investigated the susceptibility of maize kernels to attack by two common storage insects, *Sitophilus zeamais* and *sitotroga cerealella*, using the following procedure. Twenty to 35 maize populations, including soft endosperm opaque-2 maizes were rated for susceptibility to the two insects. The same populations were rated for various physical and chemical properties. The best statistical correlation was found in total protein content of the kernel. The higher the total protein, the lower the susceptibility to the insects. Neither hardness of kernel nor protein content of endosperm was as well correlated. Scientists speculate that high total protein must be



Takumi Izuno, CIMMYT staff member stationed in Pakistan and Jean Buddenhagen, assistant director of the International Institute of Tropical Agriculture, pause to exchange ideas during a tour of the Costa Rica experimental plots.

linked to the level of some unknown factor which confers resistance.

In another study a visual rating system for husk cover was developed and tested. Good husk cover is a physical barrier to insect infestation, both in the field and during storage of ears in the husk. The rating system was based on three elements: the tightness of husk, the overall coverage of the husk, and how far the husk extended beyond the ear. This system was compared with a rating system based on husk extension alone.

The test consisted of rating the husk cover by both methods. Then each ear, while still hanging in the field, was enclosed in a bag containing 20 adult insects. Two weeks later the ears were harvested, taken to the laboratory, and the number of insects emerging from the husk were counted.

The more detailed rating system proved a better indicator of resistance or husk barrier to the insects.

MAIZE PHYSIOLOGY

Physiology studies during 1970-75 have provided evidence that yield in tropical maize is limited by the number and size of grains per unit area rather than by the supply of assimilates to fill the grains. Physiology studies also suggested that the dominance of the tassel over the ear in tropical maize may be related to barrenness or smaller ears (fewer kernels). In growing periods when assimilates are limiting, the plant gives priority to delivering assimilates to the tassel. As a result, the number of florets that form and survive on the ear may be reduced.

Physiologists believe that reducing tassel size might increase the efficiency of the plant as measured in grain yield. In three advanced populations, physiologists are examining the variation for tassel size, and for time of silking and pollen release.

In another study, physiologists are looking at the relationship between efficiency and the amount of foliage above the ear. They believe that reducing the number of leaves above the ear or reducing the width of the leaves, might increase the efficiency of the plant. In drought studies, physiologists began in 1975 the first cycle of tests to determine whether families within a population have different degrees of tolerance to drought. If a practical test of difference can be found, it could be used as an added criterion in selecting the best families. Physiologists are measuring the rate of cell elongation of families under irrigation (no drought stress) and under rainfed conditions (various degrees of drought stress). These measurements are taken from the longitudinal expansion of a growing leaf. In addition the physiologists are looking for families whose potential yields under rainfed conditions are little different from their potential yields under irrigation.

CIMMYT believes that much explanatory research in maize physiology can better be performed by universities and other basic research institutions, rather than by an applied research institution like CIMMYT. But CIMMYT should continue sufficient work in physiology to fill the urgent needs in crop improvement, and to be able to interpret the progress elsewhere in basic studies. When new selection criteria for breeders are developed by outside institutions, CIMMYT stands ready to apply the new tools in its own work.

WIDE CROSSES

The breadth of germ plasma available in the CIMMYT germ plasma bank and in the breeding pools and populations provides an unusual opportu-

nity to explore the possibilities of crossing maize with related plant genera. CIMMYT's program is the largest organized attempt to make "wide" crosses and to screen the progeny for useful characters.

Wide crossing may lead to additional sources of genes for desirable maize characters, to a new crop combining features of maize and another genus or to sources of genes for desirable characters now only rarely found in maize.

The wide crossing program is still in its infancy. The work currently focuses on finding ways to break barriers to intergeneric crosses and at the same time identify strains of maize and other genera that "niche" (cross successfully).

CIMMYT is working with three plant genera in addition to maize. In 1975 several thousand crosses between maize and tripsacum were attempted. Tripsacum is a perennial which grows wild in the Americas. CIMMYT has eight species in its tripsacum garden. Some crosses between maize and sorghum were also attempted and they will be harvested in 1976. Three types of *Coix lacryma-jobi*, an old world relative to maize, were received in 1975, and crosses will be attempted in 1976.

The ninhydrin test permits screening of maize kernels for good quality protein without destroying the kernels so they can subsequently be planted.



Many combinations of maize and tripsacum produce seed, but when the seed is planted the F₁ plants are male sterile (they don't produce viable pollen) and their female fertility is low. Chromosome counts made on the F₁ plants showed that they had a full complements of maize chromosomes but that some tripsacum chromosomes were lost during the early development of the hybrid embryo and then the loss of chromosomes stops. From 26 to 42 chromosomes were found in the F₁ plants.

Since the F₁ plants are male sterile they are pollinated with maize pollen. All of these pollinations failed except for one plant that produced three seeds. When the seeds were planted, two seedlings died before chromosome counts could be made. A count made on the third plant, which died before flowering, showed that it had chromosomes from both parents.

This year's results established that tripsicum chromosomes can be transferred to CIMMYT maize materials thus making possible the use of desirable characters from tripsicum for improving maize. In the future, scientists will make more numerous crosses between strains of maize and tripsicum that produced hybrid seed in 1975, as well as attempting new combinations.

MAIZE TRAINING

CIMMYT offers several kinds of training and experience to Maize scientists from Asia, Africa, and Latin America:

- In-service training: generally 6 to 7 months residence in Mexico for candidates holding a first degree in agriculture, and under age 35.
- Master's degree program in cooperation with universities in Mexico or U.S.A.
- Predoctoral fellows: 12 to 18 months in Mexico to do their thesis research under CIMMYT supervision.
- Postdoctoral fellows: 2 years' service as an associate on CIMMYT staff.
- Visiting scientists or short-term residents.

In-service training

The maize in-service training program is only 5 years old but already 227 participants have passed through the course, including 56 in 1975. The program receives about 50 trainees per year, one fourth specializing in research skills and the rest in production agronomy.

In-service training is designed to develop skills in field research, production management, and laboratory techniques; to give experience on an inter-disciplinary team; and to teach the relationship between improved technology and development. The typical participant has had 5 to 10 years experience in a government agency, after university. The courses in Mexico stress learning by doing, "dirty hands," and

Maize in-service trainees 1971-75

Region and country	1975	1971-75	Region and country	1975	1971-75
<i>Latin America</i>	<i>18</i>	<i>103</i>	Nepal	4	9
Argentina	0	11	Pakistan	5	13
Belize	1	3	Philippines	6	14
Bolivia	1	5	Thailand	0	3
Brazil	0	3	<i>North Africa and Mideast</i>	<i>3</i>	<i>14</i>
Colombia	0	5	Algeria	0	1
Costa Rica	0	1	Egypt	2	8
Chile	0	2	Tunisia	0	1
Dominican Republic	0	4	Turkey	0	3
Ecuador	3	9	Yemen Arab Rep.	1	1
El Salvador	2	12	<i>Tropical Africa</i>	<i>20</i>	<i>65</i>
Guatemala	2	9	Cameroon	0	1
Guyana	0	1	Ethiopia	0	1
Haiti	0	3	Ghana	3	6
Honduras	5	14	Ivory Coast	2	4
Mexico	3	7	Kenya	2	2
Nicaragua	1	4	Nigeria	4	12
Panama	0	3	Tanzania	4	19
Peru	0	3	Uganda	0	1
Venezuela	0	4	Zaire	5	19
<i>South and East Asia</i>	<i>15</i>	<i>44</i>	<i>Other</i>	<i>0</i>	<i>1</i>
India	0	2			
Japan	0	3	Total	56	227

the discipline of working long hours under heat, humidity, and torrential rains.

One feature of production training is the layout of agronomic trial: on private farmer's lands, and organizing field days for farmers. This work is performed by trainees in Veracruz State under supervision of the CIMMYT training officers and the Mexican extension service. One type of trial taught to trainees is the "maize diamond" which contains four plots: 1) the farmer's variety grown with the farmer's production methods, 2) the farmer's variety grown with improved production methods, 3) an improved variety grown with the farmer's production methods, and 4) an improved variety grown with improved production methods. The range of yields within this demonstration, under Mexico's lowland tropical climate, is from 1500 to 4000 kg/ha. The demonstration helps identify the limiting factors in yield, and permits farmers at a field day to select their own technology.

Training in national programs

Starting in 1974 CIMMYT offered in-service training for officers from national programs who were preparing to give short courses for production agronomists in their own country. Eight trainers have now been trained (Ecuador-3, El Salvador-3, Philippines-1, Pakistan-1).

Alejandro Violic, CIMMYT training officer, right, gives a trainee individual instruction in an open-air classroom.



CIMMYT training staff members in Mexico are occasionally lent to national programs outside Mexico where they assist with local courses. During 1975 the director of maize training in Mexico participated in short courses for 90 production agronomists in Pakistan and 25 in Tanzania. This training role is expected to increase in future years.

Academic training

During 1975 the maize program sponsored the training of one master's degree candidate in Mexico, 12 predoctoral fellows in the U.S.A., and 12 postdoctoral fellows at CIMMYT in Mexico.

An unusual feature of academic training is the interdisciplinary advanced degree program. Such programs are now under way between CIMMYT and Kansas State University (at the M.S. level) and Cornell

University (at the Ph.D. level). In each university six or seven degree candidates from Asia, Africa, or Latin America are working on related topics for a M.S. or Ph.D. thesis. For example, a breeder, a pathologist, an entomologist, an agronomist, and an economist, may be studying closely related topics sharing each other's research, but taking their academic studies in different departments. These teams of candidates are doing their thesis research together in Mexico but receive their degrees from Kansas State or Cornell. The candidates come from nine countries (Cameroon, Colombia, Honduras, Kenya, Malaysia, Pakistan, Rhodesia, USA, and Zaire).

Postdoctoral fellows on the maize staff in Mexico have increased from five per year during 1970-73 to 10 per year during 1974-76, and the number of fellows is expected to remain at the higher level through the remainder of the 1970's. At the beginning of 1976 the postdoctoral fellows in maize came from seven countries (England 3, Germany-1, India-1, Japan-1, Netherlands-1, Nicaragua 1, USA 2).

Visiting scientists During 1975 the maize program received 12 visiting scientists and 20 short-term visitors. Visiting scientists are senior crop researchers or experiment station managers who spend 1 to 12 months at CIMMYT to become familiar with world germ plasm and CIMMYT research methods which may be used in their own national programs. Short-term visitors are agricultural policy makers and administrators who spend from a few days to 4 weeks at CIMMYT.

COLD-TOLERANT SORGHUM

In a handful of countries including Ethiopia, Kenya, and Uganda, farmers grow sorghum that is able to withstand low temperatures on high plateaus.

CIMMYT is transferring this cold tolerance into sorghum varieties suitable for farmers in areas where low temperature previously prevented sorghum cultivation. Such varieties would benefit farmers throughout the highlands of Latin America. In areas that have mild, frost-free winters, cold-tolerant sorghum could broaden the cropping options open to farmers. And in areas where sorghum can be grown but is risky because of an occasional cold snap, or because of low soil temperature at planting time, cold-tolerant sorghums could stabilize farmers' incomes. The ability of sorghum to withstand moderate drought is an added advantage.

Breeders in Mexico have conducted research on cold-tolerant sorghum since 1954. But only in 1973 was a breeder assigned full-

time. CIMMYT's sorghum research will be conducted in collaboration with the International Crops Research Institute for the Semi-Arid Tropics in India.

**Germ plasm for
cold tolerance**

*Cold-tolerant
sorghums being
developed at
CIMMYT will
broaden the
cropping options
of farmers in
high-altitude
areas.*

The first cold tolerant lines in Mexico can be traced to three sorghum varieties from East Africa. These were the first sorghums to bear seed in the Western Hemisphere above 2000 meters elevation. Since 1973 CIMMYT has obtained over 150 additional lines from the highlands of Ethiopia. Based on trials at El Batan (2200 m) perhaps three-fourths have cold tolerance. Because the African lines are daylength-sensitive and will not flower during the Mexican highland growing season, CIMMYT breeders must first make crosses to produce progeny that are insensitive to daylength, after which they can be tested for cold tolerance.



- Breeding** African germ plasm which carries cold tolerance is undesirably tall (sometimes over 4 meters) and is likely to lodge. It also needs added sources of disease resistance, insect resistance, better protein quality and other desirable characters.
- Few diseases of sorghum exist in the Mexican highlands but all sorghums in the CIMMYT program are evaluated at CIMMYT's humid low-land station at Poza Rica where diseases caused by *Cercospora*, *Puccinia*, *Sclerospora*, *Helminthosporium*, and *Diplodia* are important problems. Good sources of resistance to all diseases identified at Poza Rica exist in both cold-tolerant and cold-susceptible sorghums.
- In 1976 cold-tolerant selections from CIMMYT will be sent to Texas A & M University (USA) for screening against anthracnose, downy mildew, and head smut.
- For genetic resistance to insects, sorghum lines are being screened against maize leaf aphids, midge, and fall armyworm. Sorghums with resistance to greenbug and midge have been obtained from Texas and crosses are being made in Mexico.
- Nearly 3000 sorghum crosses were made at CIMMYT in 1975. Most crosses for disease and insect resistance, or other characters, reintroduce cold susceptibility. Fewer than 5 percent of the progenies in early, segregating generations combine both cold tolerance and the other desirable characteristics which are being sought.
- Protein quality** The protein of normal sorghum has low lysine content (2 percent of protein, similar to normal maize). CIMMYT breeders are using high lysine lines from Africa and an induced mutation identified at Purdue University (USA) to improve the nutritional value of sorghum.
- Sorghum lines from East Africa carrying high lysine are tall and daylength-sensitive and their grains are opaque—an undesirable characteristic for acceptance by farmers. Starting in 1974 crosses were made to provide shorter progeny, with daylength insensitivity, that could be used as parents in crosses with cold-tolerant sorghums. In 1975 breeders found that some grains from the F_2 segregating populations had normal (shiny) appearance and lysine content as high as 3.0 percent. These lines also had lower than-normal protein percentage. Breeders believe that normal protein content can eventually be regained while retaining high lysine content.
- International testing** Sets of up to 380 cold-tolerant lines were sent to 29 locations throughout the world for testing in the summer of 1975. The trials will provide valuable information on cold tolerance, disease and insect resistance, and general adaptation. The best performing 30 lines have been sent out again for replicated yield trials in 1976.

The sorghum work at CIMMYT has achieved faster progress than anticipated, and varieties with greatly improved characteristics should be ready for commercial use by 1980.

COOPERATION WITH NATIONAL PROGRAMS

CIMMYT continued its cooperation with national maize programs through a variety of methods.

The maize staff spent 1207 man-days in 1975 (about 3.5 man-years) consulting with governments of maize-producing countries of Asia, Africa and Latin America, or discussing basic research at other research institutions. This consultation includes participation in regional workshops, where research plans are made for the following year; observation of CIMMYT nursery materials grown by national programs; visits to commercial crops in farmers' fields to identify constraints, meetings with national policy makers to discuss fertilizer supplies, maize prices, and other policy questions.

CIMMYT experimental nurseries continued to supply advanced populations for almost every maize-producing country in the developing world.

Ten members of the CIMMYT maize staff were stationed in five national research and production programs in 1975: Egypt, Nepal, Pakistan, Tanzania, and Zaire. Guatemala will be added to this list in 1976, when two CIMMYT staff are posted there.

Arrangements for the posting of CIMMYT staff to major maize-growing regions of the world gradually took shape during 1975. Two maize scientists gave full time to Central America and the Caribbean region. A regional maize program for the Andean region, jointly sponsored by CIAT-CIMMYT, will begin operations in 1976, with three CIMMYT staff members residing in the region. A regional program for South and Southeast Asia will be headquartered at ICRISAT in India, and begin operations in 1976. CIMMYT and IITA (Nigeria) have worked out a pooling of their maize efforts in tropical Africa.

Each regional effort involves a similar pattern of activities: regional staffing, regional nurseries, regional workshops, assistance to training within national programs, and an annual progress report to help stimulate the national program efforts.

1976-80 FORWARD LOOK FOR MAIZE

At an internal program review, held at El Batán in late 1975, the CIMMYT staff discussed their aims and expectations for the maize

program over the 5-year period 1976-80. Some staff scientists advised against any predictions. But the following points received general support:

(1) Advanced maize materials tested at CIMMYT research stations in Mexico and in national programs outside Mexico, will show annual continuous improvement during 1976-80, measured by shorter plant height, improved disease and insect resistance, wider maturity range, better protein quality, and higher yields. These improvements are objective and can be seen best in the annual performance of elite varieties.

(2) Quality protein maize will achieve substantial commercial use by 1980, both for human food and animal feed.

(3) By 1980 experimental varieties will be distributed by CIMMYT suitable for three climatic zones (tropical lowland, tropical highland, temperate), three maturities (early, medium, late), and major kernel types. This means that gaps remaining in the CIMMYT pools and populations of 1975 will be filled by 1978, and will generate experimental varieties by 1980.

(4) Collaborative research on maize diseases will be emphasized. Resistance in the advanced populations to downy mildew (Asia), maize streak virus (tropical Africa), and maize stunt (tropical Latin American nations) needs to be far superior to that presently available. The improvements will result from collaboration between six national programs and CIMMYT.

(5) By 1980 national maize programs within 30° N and 30° S will receive most of their new germ plasm for open pollinated maize through CIMMYT experimental variety trials. This was substantially true in 1975 but the proportion will increase. As time goes on, many of the improved varieties should be generated by national programs, and made available through world-wide trials.

(6) CIMMYT's regional maize programs (Central America, South America, tropical Africa, South Southeast Asia) will be fully operative before 1980, in cooperation with other centers. Stronger national programs will be giving help to neighboring countries through the initiative of CIMMYT's regional staff.

(7) Many governments will be giving more effective attention to increased production of food crops, including maize, sorghum, and barley. In past, some governments focussed only on wheat and rice, because of national food preference. Now food habits are changing as population grows.

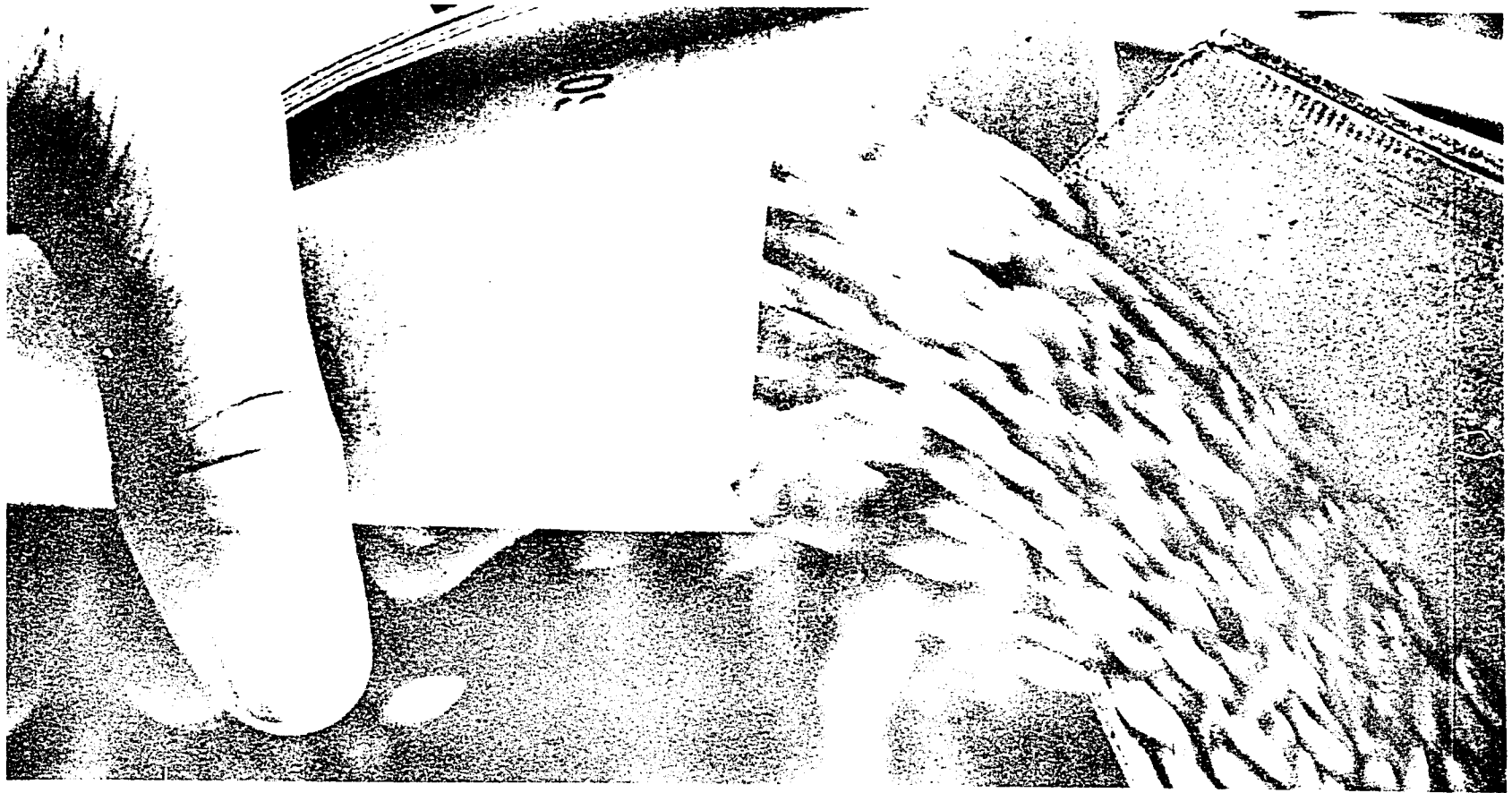
(8) The world network of scientists working on maize will be substantially improved during 1976-80, both in numbers and skills.

(9) The world maize crop of 1975 is waiting to benefit from a backlog of technology not yet in use; this situation is comparable to

the world wheat crop of 1962 (year of the first Mexican semi-dwarf wheats) and the world rice crop of 1965 (year of the IRR1 variety IR-8). A revolution in maize yields could begin during the half decade 1976-80.

(10) CIMMYT is willing to have its maize program judged during the last half of the 1970's by (a) the performance of new maize varieties in the research stations, and (b) the rising yields in farmers' field across producing areas and over years. We realize that (a) can be wholly credited or blamed upon scientists. Whereas (b) requires the supporting actions of many governments in regard to agricultural resources, agricultural policies, and maintenance of public order. Only a combination of better technology and better government performance will enable farmers to produce higher yields.

wheat improvement



INTRODUCTION

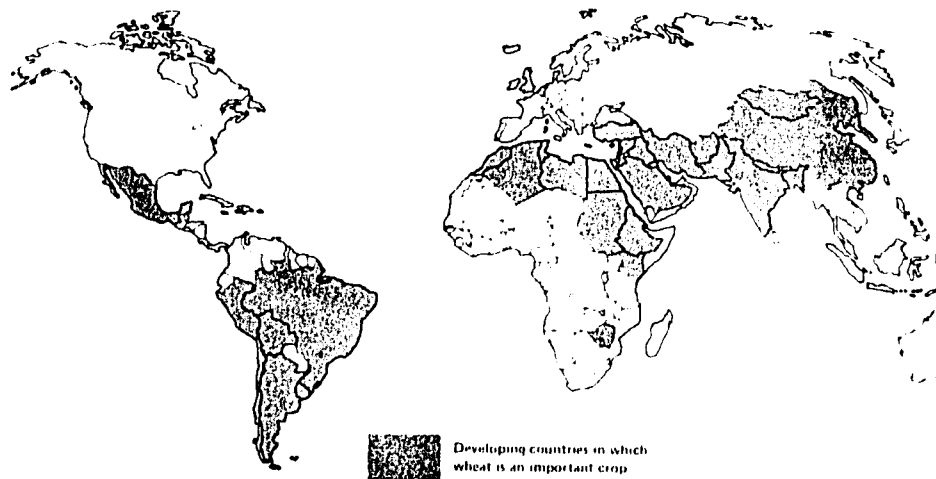
Wheat ranks first among world food crops, measured either by planted area (225 million hectares) or by size of harvest (360 million metric tons):

Wheat	360 million tons
Paddy rice	323
Maize	293
Barley	171
Sorghum	47

In international trade, wheat and wheat flour constitute the largest food commodities. In 1973 FAO reported that half the cereals imported into food deficit areas consisted of wheat and wheat flour (78 million tons, US\$8 billion value).

The center of origin for wheat was in the Mideast, near the cross point of national boundaries for USSR, Turkey, Iraq, and Iran. Most of the small grains (wheat, barley, oats, rye) were first domesticated in this vicinity. They were carried by early man to the outer reaches of the Eurasian continent, and later by European explorers to all the continents except Antarctica. Today a network of scientists in more than 100 countries is working to improve the small grains.

High and stable yields for wheat on a world-wide basis appear to be a keystone in approaching many basic human problems, including food shortages, farmer incomes, holding down the basic food costs of the city dweller.



Wheat in developing countries

Twenty percent of the world's wheat crop is harvested in developing countries (72 million tons). Developing countries in which wheat is a major crop (1974 data) include:

	<i>Asia</i>
Afghanistan	3.0 million tons
India	22.1
Iran	4.1
Iraq	1.3
Pakistan	7.6
Syria	1.6
Turkey	11.1
Other	39.2
Total	90.0 million tons

	<i>Africa</i>
Algeria	0.9
Egypt	2.0
Ethiopia	0.8
Morocco	1.9
Tunisia	0.8
Other	2.1
Total	8.5 million tons

	<i>Latin America</i>
Argentina	5.6
Brazil	2.8
Chile	1.0
Other	3.6
Total	13.0 million tons

It was in developing countries that the phase "green revolution" first appeared. Yet 10 years after the revolutionary changes began, the average yield of wheat in developing countries is 1100 kg/ha, whereas the average yield in industrialized countries is 2100 kg/ha. The difference in average yields provides a target for future wheat improvements in Asia, Africa, and Latin America.

Short program history in Mexico

Norman Borlaug arrived in Mexico in 1944 as crop pathologist for the Office of Special Studies (cooperative program between the Mexican Ministry of Agriculture and the Rockefeller Foundation). In those days stem rust was the most devastating disease of wheat, causing periodic epidemics which were national disasters. Mexico was importing half its wheat requirements. Within 5 years Borlaug and his Mexican colleagues had developed several new varieties of bread wheat which carried substantially greater rust resistance than had ever been seen in Mexico before. By 1956 Mexico was self sufficient in wheat.

Several unusual research procedures contributed to this early progress:

1) Wheat breeding was conducted two cycles a year, one a winter season crop in northwest Mexico at sea level, and latitude 27°N, the other a summer season crop on the central plateau of Mexico, at latitude 19° N and elevation 2600 meters. This migration north and south, twice a year, speeded up work; and it brought important side effects, eliminating daylength sensitivity in the experimental wheats, and developing wider adaptation.

2) Borlaug drew upon the entire U.S. world collection of wheat germ plasm (26,000 items); he screened that collection many times in search of disease resistance and other characters; he made thousands of single crosses, double crosses, back crosses, top crosses to pyramid the genes. He developed a massive numbers game, not guided by the cytologist's microscope but by the observation of millions of plants in the field. Up to the 1950's, no other plant breeding program in history had made such massive use of a world collection and had generated so many tens of thousands of crosses.

3) Heavy selection pressure for disease resistance was achieved in the program by natural pathogens and by artificial inoculation.

4) Breeding plots were irrigated whenever necessary to ensure the survival of experimental wheats, and to observe their performance under optimum conditions. But after the F₂ (second generation) the wheats were tested under both irrigated and rainfed conditions, often on private farmlands, to observe their performance under conditions facing the farmer.

These methods produced early progress against rusts.

The staff next set out to produce varieties with stronger straw, to reduce lodging. A breakthrough was obtained by the use of a single dwarfing gene from the Japanese variety, Norin-10. This Japanese Mexican product produced the first semi-dwarfs released by Mexico in 1962. Other genes were added later, to produce a wide array of dwarf wheats.

Along with short stiff straw came greater nitrogen responsiveness. Old tall wheats usually gave 3 kilograms of increased grain for every kilogram of nitrogen. The newer shorter more efficient varieties gave as much as 10 kilograms or more of increased grain for every kilogram of nitrogen, under good management. This explains several side effects of the "green revolution." There was a sudden rise in fertilizer demand. And some farmers who enjoyed greater income from the new wheats could afford tubewells and other irrigation facilities for the first time. Thus there was a spillover effect into broader rural change.



Two veterans of the wheat fields: Norman Borlaug, right, and Reyes Vega, who has probably made more wheat crosses than any man in history.

The earlier Mexican wheats were tested in Latin America in the 1950's, through Rockefeller cooperative programs in Colombia, Ecuador, and Chile. Regional nurseries were started there, and workshops held for scientists of the region. This was the beginning of a network.

By 1960 FAO was sending young wheat scientists from the Mediterranean and mideast for training in Mexico. Borlaug and his Mexican colleagues began consulting trips to Asia and Africa, as well as Latin America. More nurseries were established, more workshops held. Thus a program devoted originally to Mexico acquired world focus.

New commodities were added. Triticale research began in Mexico in the mid-1960's. In 1968, work on durum wheats was greatly

expanded, borrowing the dwarfing technique and the dwarfing genes from bread wheats. In 1972 work was resumed on barley as a foodcrop. Barley work had been suspended 10 years earlier when the wheat staff became engrossed in the distribution of dwarf bread wheats.

Remaining problems

Even if future population growth is ignored, problems facing the wheat program remain formidable in the mid-1970's.

1) Stable resistance to the three rusts has still eluded the researchers. New approaches are showing progress.

2) Septoria, a fungus disease which causes major epidemics in the mideast, North Africa, and South America, is another problem awaiting effective control. Wheat lines with good resistance to septoria entered CIMMYT's international nurseries for the first time in 1975.

3) Only 35 percent of the wheat lands in developing countries are so far planted with high yielding varieties and appropriate packages of cultural practices. Much of the remaining 65 percent represents ecological "niches" that still lack new wheat varieties tailored to their needs. Some niches require varieties with tolerance for low or high temperatures, some need shorter maturity, some need faster ripening qualities (for Algeria and neighbors), some need tolerance to soil aluminum (Brazil), some need greater resistance to local diseases and insects. All these problems are receiving attention, either in Mexico or through the network.

4) Drought tolerance is a characteristic that would benefit a vast number of farmers in rainfed regions. Since 1972 CIMMYT has been making thousands of crosses between winter-type and spring-type wheats, hoping that the deeper crown root of the winter wheats, and their greater tolerance to droughts, can be transferred to the spring wheats. Advanced lines from these winter-spring crosses will reach the international yield trials for the first time in 1977.

5) High yielding durum wheats--far higher than any available 7 years ago--are now being released to farmers by national programs but much needs to be done to achieve stability of yields.

6) Food barleys have moved only half way up the pathway previously followed by the bread wheats.

7) Triticale breeders are rapidly broadening the germ plasm base for their man-made cereal, and watching the steady improvement of plant type, disease resistance, and yield. They have crowded into one decade much of the development process which took thousands of years of natural evolution in wheats. The commercial introduction of triticale has begun, but full benefits are still ahead.

BREAD WHEAT

The bread wheat researchers aim to develop varieties that produce stable high yields over a wide range of environments. Stability requires disease resistance. Wide adaptation requires daylength insensitivity.

Worldwide, three major rust diseases and septoria (fungus diseases) are the major barrier to stable yields. Races of each rust are capable of mutation so that a wheat variety with genetic resistance to the predominant races will become susceptible to a new race within a few years. A high yielding bread wheat variety which carries resistance to one or all of the three rusts usually lasts no more than 2 to 10 years before a new race overcomes its resistance. Farmers then switch



Shaking the pollen from one spike onto the flowers of another spike has cut the time needed for making a cross compared with conventional methods.

to other varieties. A few varieties have remained disease resistant for decades but their yield potential is lower than present-day varieties. For example, the tall Mexican variety Yaqui-50 has been resistant to stem rust for 25 years. Such varieties are used as parents in the bread wheat program to introduce stable resistance to varieties that have high yield potential.

Some of the newer semidwarf wheat varieties are still resistant to stem rust as much as 10 years after they were released (for example, INIA 66). Many of CIMMYT's advanced lines also appear to be resistant in many locations throughout the world. The level of stem rust resistance in CIMMYT bread wheat varieties and advanced lines thus seems to be approaching a horizontal type of resistance. This has been achieved by inoculating millions of F₂ plants with numerous stem rust races to eliminate susceptible plants, and by crossing hundreds of resistant varieties and testing the progeny for rust resistance at dozens of locations throughout the world.

The level of resistance to leaf rust and stripe rust in CIMMYT-developed wheats does not, however, compare to their resistance to stem rust. CIMMYT is placing priority on raising resistance to leaf and stripe rust. Most released Mexican semi-dwarf wheats have become susceptible to these two rusts within 3 years, with the exception of Tobar 66. Some lines in advanced testing, however, have shown resistance to leaf rust races at over 30 locations worldwide.

In the cool moist climate of Toluca during the summer season, natural and severe epidemics of rust develop. In the dry winter climate of Sonora, CIMMYT artificially inoculates for stem and leaf rust. Thus experimental wheats are under selection pressure for disease resistance two cycles a year.

Apart from conventional resistance breeding CIMMYT employs two other approaches to disease resistance: the multiline and slow rusting.

1975 breeding and testing

Thirteen hundred advanced lines of bread wheat were yield tested at Ciudad Obregon in 1975 and the best 386 were selected for inclusion in the 9th International Bread Wheat Screening Nursery (IBWSN). The lines in this nursery are advanced generations from about 200 crosses of a total of about 5000 made in 1971-73. Their yields were 6500 to 9000 kg/ha at Ciudad Obregon under experiment station conditions.

About 30 percent of these lines carry strong resistance to septoria, a fungus disease important in the Mediterranean region and South America. This is the first large group of septoria-resistant lines distributed through an international nursery.

The resistant lines were selected from screening in Patzcuaro, Mexico, where *Septoria tritici* is epidemic. Previous testing showed that lines resistant in Patzcuaro are likely to be resistant in Turkey and Algeria which also have *Septoria tritici*. Brazil however has a complex of both *Septoria tritici* and *Septoria nodorum* plus soil toxicity problems. Under those conditions, Mexican advanced lines are still very unsatisfactory.

The 9th IBWSN was sent in the summer of 1975 to 150 locations, worldwide, to be planted in the winter season of 1975/76, and data to be returned during 1976.

Variety releases The Mexican government released three new CIMMYT-INIA bread wheats in 1975. Cocoraque 75 is a sister line of Jupateco 73, but is more resistant to leaf rust. Salamanca 75 is a soft biscuit-type wheat with good rust resistance. A slightly weak crown root makes Salamanca somewhat susceptible to lodging. Zaragoza 75 is a late maturing one-gene dwarf with red grain, highly resistant to leaf rust but susceptible to stripe rust. All three of the 1975 releases are susceptible to septoria, but this is not a serious problem in Mexico.

Outside of Mexico, numerous bread wheats of Mexican origin were released in 1975. A partial list:

Argentina --Precoz Parana INTA, Diamante, Leones INTA.
Cyprus --Jaral 66 "s", Blue Silver, Mexipak.
Guatemala --Maya 75.
Nepal --NL30
Pakistan --Lyalpur 73, Sandal.
Paraguay --Jacal 66 "s"
South Africa --Sonderend
Tunisia --Carthage, Dougga
Turkey --Cumhuriyet, Sakarya (chanate 2), Jehan, Nuri 70.
USA (Colorado State) --Colano.

Multilines Bread wheat varieties derived from cross 8156 (a Mexican cross made in 1957) have been grown on more than 13 million hectares over 5 continents. It is widely recognized that the use of one variety on large geographical areas presents a potential danger since a single rust race could cause widespread destruction. Further it has been demonstrated by aerobiological studies that an epidemiological zone can cover substantial areas. Nevertheless, a variety with such superior performance and wide popularity could continue to provide high yields if this disease danger could be reduced. This is the argument for the multiline.

In 1971 CIMMYT initiated a program to diversify the disease resistance in this basic genotype. Varieties drawn from USA, Canada, Argentina, Colombia, Ecuador, Kenya, Australia, India, Rhodesia,

North Africa, and other countries, contributed different sources of resistance for the three rusts and septoria.

In 1975, 215 advanced lines were produced, and distributed as the 4th International Multiline (8156) Nursery to more than 30 locations where this variety is well adapted.

One set was planted in Toluca 1975. The 111 entries which survived stripe rust at Toluca will be individually yield tested at Ciudad Obregon in 1975/76 together with 12 different composite multilines. It is expected that these yield data can be used to form composites for Mexican conditions.

Three recent trials of the 8156 multiline can be reported. In 1974/75 yield trials were held at Ciudad Obregon for seven composites of 8156. Yields of the composites ranged 7300 to 8000 kg/ha, while Siete Cerros (a Mexican white-grain 8156 variety) was used as a check, and gave yields of 7500 to 8400 kg/ha. In another trial, two of the above composites from 8156 were tested at 15 sites, worldwide, in 1975. The composites averaged 4400 and 4500 kg/ha, while Siete Cerros gave 4300 kg/ha over all sites. These two composites were also tested in the Ciudad Obregon

Selected spring bread wheat varieties bred by CIMMYT-INIA or predecessors, released by Mexico, 1950-75.

Year of Mexican release	Variety name	Year of cross	Yield potential ^a kg/ha	Plant height ^a cm	Disease rating in Mexico 1975 ^b			
					Stem rust	Leaf rust	Stripe rust	Septoria
1950	Yagor 50	1945	3500	110	TMS	20MS	10MS	MR
1960	Namati 60	1958	4000	110	10MS	5R	0	
1962	Pitic 62	1956	5370	100	100S	60S	80S	MR
1962	Penjamo 62	1956	5870	100	50MS	0	80S	MR
1964	Sonora 64	1957	5580	85	20MS	70S	80S	S
1964	Lerma Rojo 64	1958	6000	100	30MR	80S	80S	S
1966	INIA 66	1962	7000	100	5MR	100S	80S	S
1966	Siete Cerros	1967	7000	100	TMS	20S	100S	S
1970	Yecora 70	1966	7000	80	TR	100S	100S	S
1971	Cajeme 71	1966	7000	80	TR	100S	100S	S
1971	Tanori 71	1968	7000	90	20MR	80S	60S	S
1973	Jupateco 73	1969	7000	95	TMR	TMR	60S	MR
1973	Torim 73		7000	75	TMR	20MS	40S	S
1975	Cocoraque 75	1969	7000	90	TR	TR	20MR	MR
1975	Salamanca 75		7000	90	TMR	20MS	20MS	S
1975	Zaragoza 75		8000	90		30MR	80S	S

^a Measured at experiment stations in Mexico, irrigated, and essentially disease free. ^b All varieties were resistant to all three rusts under Mexican conditions at time of release. R = resistant; S = susceptible; 0 = no rust; MR = moderately resistant; MS = moderately susceptible; 20MS = 20% of sample is moderately susceptible, balance is resistant; TMS = a trace of sample is moderately susceptible, balance is resistant; TR = a trace of sample is resistant, balance is susceptible.



After Matt Mc Mahon, CIMMYT agronomist, above right discusses an on farm weed control trial, wheat trainees get experience in identifying weeds



research station in 1975, using four commercial varieties as checks. The composites gave yields of 9400 and 8600 kg/ha; the commercial varieties yielded 8100 to 9100 kg/ha.

These trials confirm the basic principle of the multiline. But much work remains to develop separate multilines for major producing nations, using local selection of components for each multiline, and local seed increase.

Slow rusting Most bread wheat varieties have major-gene resistance which is specific to the predominant rust race in an area, but when the predominant race changes, the resistance conferred by the major gene is likely to be ineffective against the new race.

Varieties such as Yaqui 50 are relatively unaffected by changes in rust because the plants develop pustules whose appearance would ordinarily cause a pathologist to rate the plant susceptible, but the pustules develop more slowly than normal. Because there are fewer spore-producing pustules, the disease develops slower and the plants escape serious damage.

Pathologists began in 1975 to develop ways to measure slow rusting in an attempt to identify lines with the greatest degree of slow rusting. Since slow rusting probably results from the additive effects of several minor genes, lines that rust the slowest presumably have more genes for slow rusting. These lines can be used in crosses with higher yielding dwarf wheats that already have race specific resistance. Working with leaf rust, pathologists found they could identify slow rusters by rating plants three times a season. Among the slow rusters the best lines could be identified by protecting some plants with a fungicide, and comparing their grain weight with that of plants of the same line grown without fungicide. Those lines in which disease caused the least reduction in grain weight are the slowest rusters.

Among 14 entries examined for leaf rust in preliminary tests in 1975, Bonza 55, a tall Colombian variety was the slowest rustier—even better than Yaqui 50, another tall variety. In 1976 pathologists will test 39 lines including many slow-rusting dwarf wheats. Although tall varieties such as Yaqui 50 are already being used as sources of slow rusting, identification of more and better slow-rusting dwarf varieties would speed the process of breeding high yielding, adaptable dwarf wheats with slow rusting. The preliminary tests in 1975 indicated that two dwarfs, the variety Torim 73 and the advanced line Kal-Bb, have intermediate slow rusting characteristic to leaf rust.

Spring x winter wheat The terms spring-type and winter-type bread wheat loosely refer to the times of year at which these wheats are planted. Winter wheats need

a period of cold to induce flowering. They are also quite cold resistant before flowering. As a result they are planted in the autumn in areas that have fairly cold winters. Spring wheats do not require a cold period to induce flowering. They are planted in the spring in areas that have a winter that is too cold for winter wheats to survive or they are planted in the autumn in areas that have a winter that is too mild to induce flowering in the winter wheats.

Spring wheats and winter wheats have been bred as separate groups because their different ecological requirements make crossing difficult, and they have evolved different characteristics. Today winter wheats are better than spring wheats in resistance to septoria and stripe rust and in drought and cold tolerance, while spring wheats are better in stem rust resistance and bread-making quality.

Large-scale field crossing of spring wheats with winter wheats became possible when CIMMYT discovered in 1972 that both types could flower simultaneously in the field at the Toluca experiment station. Because of Toluca's 2600-meter altitude, the weather in December is cold enough to induce flowering in winter wheats planted in November. The weather is also warm enough after mid January to permit planting of spring wheats in the same field. The two groups flower side-by-side in May and June, allowing vast numbers of crosses to be made. In 1975 over 2000 successful crosses between spring and winter wheats were completed.

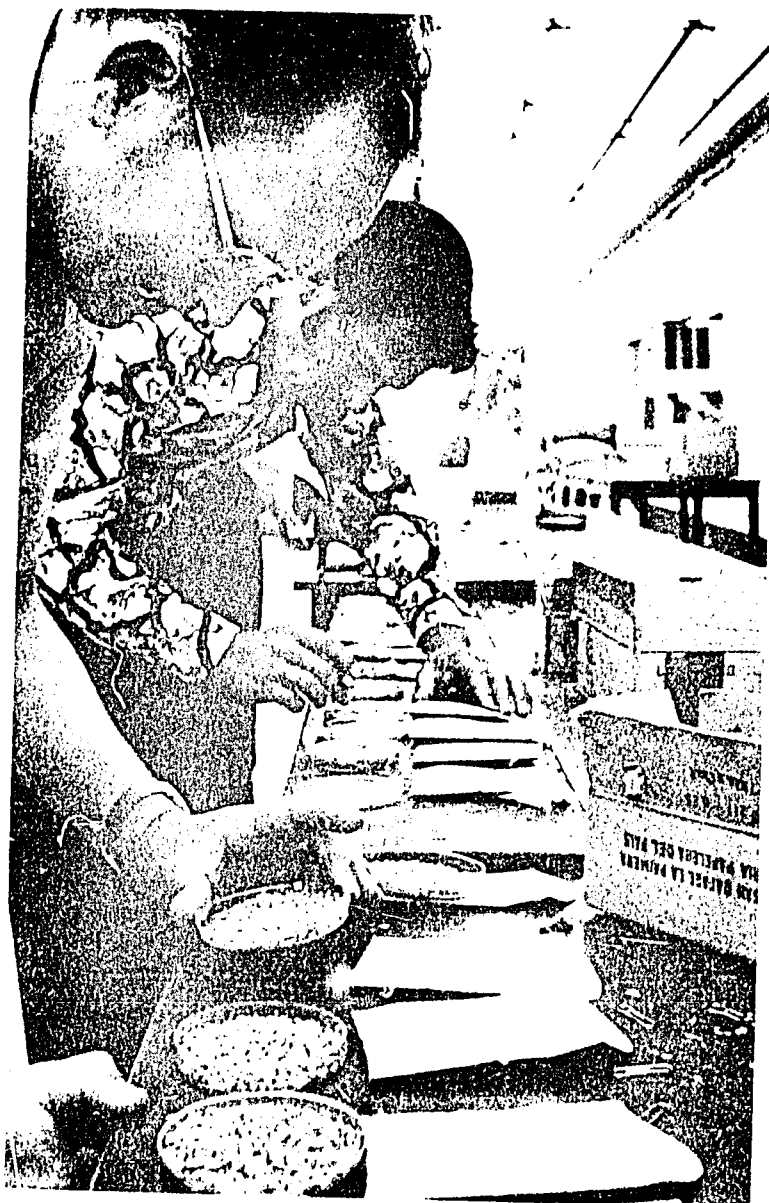
From these crosses a portion of all F₁ seed is sent to Oregon State University (USA) where plant scientists select winter wheat types that have desirable features transferred from spring wheats. They make crosses to other winter wheats or to other winter x spring lines for distribution to the winter wheat growing areas of the world. Some F₁ seed is also sent from CIMMYT to scientists in Turkey and India.

The F₁ seed retained by CIMMYT is top-crossed or double-crossed to spring wheats grown at Ciudad Obregon and Toluca. Breeders select for spring types that have desirable features transferred from winter wheats. About 40 percent of the progeny are discarded the first year because of disease susceptibility or excessively late maturity. The best remaining progeny show increased yield, increased drought resistance, and a wider range of maturity than traditional spring wheats.

Many scientists throughout the world are now able to work with spring x winter germ plasm because CIMMYT distributes F₂ bulk spring x winter seed to 100 locations as part of its F₂ seed distribution program.

Crosses made at CIMMYT in 1972 are now reaching the F₄ stage. By 1977 the best advanced lines will enter the International Bread

*Rating the grain
of individual
plants from
segregating
generations.*



Wheat Screening Nursery for the first time. This might reveal a research breakthrough for wheat improvement in the 1970's.

Lines from the spring x winter bread wheat crossing program are already used as parents by triticale and durum breeders, to increase the variability in those two crops.

F₂ distribution	<p>Under the F₂ distribution program, begun in 1972, CIMMYT sends second generation seeds to national wheat scientists who can select from the segregating populations the plants that perform best locally. This program is especially helpful to nations that do not have large crossing programs.</p> <p>In 1975, CIMMYT bread wheat breeders grew 3000 F₁ crosses at Ciudad Obregon. After discarding 2000 F₁ plants that were susceptible to rust or that had poor plant type, the F₂ progeny were classified for testing under dryland (rainfed) or irrigated conditions. Seeds of those F₁ crosses which had shown rust resistance, which involved parents which had septoria resistance, and which grew more than 100 centimeters tall were sent to dryland areas where septoria resistance is essential in addition to rust resistance (e.g. Algeria, Turkey, Tunisia, Argentina). The progeny of the F₁ crosses which grew less than 100 centimeters tall and had rust resistance were sent to irrigated areas of the world (e.g. North India, Pakistan, Rhodesia, Mexico). In all, 100 locations received F₂ populations.</p>
International yield nursery	<p>Each year since 1964, CIMMYT has assembled a group of 50 varieties to form the International Spring Wheat Yield Nursery, a replicated yield trial. It is currently being sent to 120 locations in more than 70 countries.</p> <p>This yield trial has uncovered the mechanism involved in adaptation for yield, it has helped identify broader based resistance, and, most important, it has provided cooperators with a wide array of germ plasm suitable for release as varieties or for use in breeding programs.</p>
Crossing block and other trials	<p>CIMMYT distributes a number of other nurseries for trials by breeders in national programs.</p> <p>The crossing block is a group of carefully chosen wheat lines and varieties, each entry being one of the world's best sources for at least one desirable characteristic. Seed of 250 entries was sent to 50 locations in 1975 so that breeders can evaluate them under local conditions and use them in crosses if they wish. Several lines that have resistance to aluminum toxicity, a serious soil problem in some regions, were included in the crossing block in 1975.</p> <p>Two regional screening nurseries are coordinated by CIMMYT. One is the Regional Disease and Insect Screening Nursery, serving countries from India to Morocco. The other is the Latin American Disease and Insect Screening Nursery. The latter began in 1975. Both aim to find broad disease resistance in experimental wheat lines.</p> <p>A trap nursery of commercial wheat varieties of the Eastern Hemisphere is grown throughout the Mediterranean and Mideast, to</p>

assess the vulnerability of commercial varieties to new races of rust and other diseases which spread across international borders.

Aluminum toxicity

Soils in some areas of the world contain levels of aluminum that are toxic to most wheat varieties. The problem is severe in parts of southern Brazil. Several tall Brazilian wheat varieties survive in soils with high aluminum content but are not high yielding. Since 1974 CIMMYT has cooperated with FECOTRIGO, a Brazilian research organization, by planting their F₁ seeds at Ciudad Obregon so that large numbers of double crosses can be made with CIMMYT F₁ plants. In 1975 this bilateral international cooperation was extended to EMBRAPA, another Brazilian national institution, and a more vigorous crossing program is being attempted. Part of the resulting seed will be maintained at CIMMYT for selection, but the bulk of the seed will be shipped to Brazil to accelerate wheat improvement there.

Wheat for the humid tropics

Wheat and wheat flour are major imports for many countries in the humid tropics. Several countries are investigating the potential for growing wheat in their "winter" season - the period of lowest humidity and temperature.

To help these areas, CIMMYT in 1974 began screening wheat germ plasm at its lowland tropical experiment station at Poza Rica. Tests in 1974 and 1975 showed that Siete Cerros, the world's most widely planted wheat, is the best agronomically adapted variety under warm tropical weather conditions, but it is susceptible to the fungus disease *Helminthosporium sativum*. This is the foremost disease problem at Poza Rica and other tropical areas. To find sources of resistance, 6000 lines from the world wheat collection were grown at Poza Rica in 1975. The varieties Sturdy and Horizon were found to have a degree of *Helminthosporium* resistance. Crosses were made to many Mexican varieties, and the F₂ progeny will again be tested at Poza Rica.

Much more information is needed on the behavior of wheat in the humid tropics before this exploration can move to commercial scale. But results so far are promising.

DURUM WHEAT

Durum wheat is an important food around the Mediterranean, in the mideast, parts of India, USSR, USA, Canada, Argentina and Chile. In developing countries durum is usually consumed as

Durum varieties released in Mexico between 1950 and 1975.

Year of Mexican release	Variety name	Year of cross	Yield potential ^a kg/ha	Plant ht. ^a cm	Disease reaction ^b				Sept. tritic	Test weight kg/hl	Pigment ^c ppm
					Stem rust	Leaf rust	Stripe rust				
1941	Barrigon-Yaqui	<i>d</i>	4000	130	0	TS	70S	R		75	4.5
1960	Tehuacan 60	1954	4200	150	0	10MR	20MS	R		81	5.5
1965	Oviachic 65	1960	7000	90	0-40MS	30S	5MR	S		81	7.2
1967	Chapala 67	1961	7000	85	0	10MS	10MR	MS			4.0
1969	Jori C 69	1963	7700	85	0	TR	5MS	S		81	3.7
1971	Cocorit 71	1965	8300	85	0	5MR	5MS	MS		81	3.6
1975	Mexicali 75	1969	8600	90	0	TR	5MR	S		78	5.8

a/ Measured at CIANO experiment station, at high rates of fertilizer with irrigation, and in the absence of diseases. *b/* In Mexico, 1975. R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible. Figures before letters indicate percentage of infection. *c/* Carotinoids. *d/* Farmer's selection.

couscous, bread, chapatis, and more rarely, as macaroni and other pasta products. For such countries good pasta-making quality is not highly important except in countries which export durum to Europe.

Durums were first dwarfed in Mexico in the early 1960's by crossing tall durums with dwarf bread wheats. In 1968, CIMMYT expanded its work on durums and durum progress in the 1970's has been notable.

Since 1968 CIMMYT breeders have been able to produce durum lines with vastly higher yield potential and wider adaptation. The best durums now equal the best bread wheats in yield.

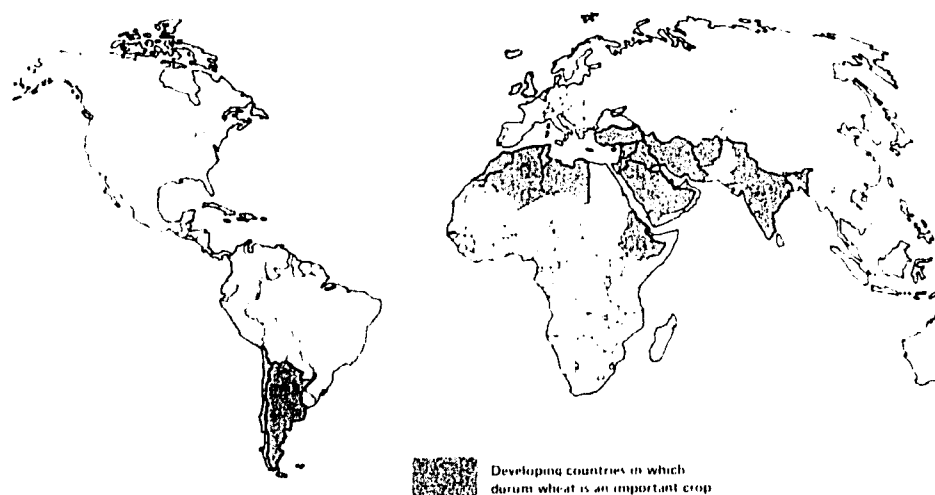
The linkage of the dwarfing gene with sterility in durums has been weakened but not totally erased.

Breeders have identified sources of disease resistance, especially resistance to rusts and septoria, which are being crossed with high yielding dwarf durums.

Cooperation among durum breeders has hastened the release of high yielding varieties. CIMMYT acts as a coordinator and catalyst for international testing.

Several national programs in the Mediterranean and Near East regions have released Mexico-bred durum varieties. These include:

- Algeria — Cocorit, Jori.
- Cyprus — Amel, Maghrebi.
- Iraq — Cocorit, Jori.
- Lebanon — Cocorit, Jori.
- Saudi Arabia — Cocorit, Jori.
- Tunisia — Amel, Maghrebi.
- Turkey — Dicle, Gediz.



Better fertility

As in bread wheats, the introduction of the Norin-10 dwarfing gene caused some sterility in durums. The development of Cocorit (1971) showed that the linkage between dwarfing and sterility might be broken. In the variety Mexicali (1975) the linkage to sterility was further reduced. Nevertheless durums still have lower fertility than bread wheats. This means that durum spikes contain a higher proportion of empty spikelets than do bread wheats. The best durums are able to equal the best bread wheats in yield because the weight of each grain for durum wheat is normally heavier. If more spikelets were filled, durums might substantially outyield bread wheats. An extra penalty of dwarf durum's tendency toward sterility is that moisture stress during drought increases the number of empty spikelets. Durum breeders are increasing their emphasis on higher fertility. In 1975, they began testing methods for quickly assessing fertility in early generation.

Disease resistance

None of the highest yielding released durum varieties can be considered strongly resistant to rust diseases or septoria. Resistance is especially needed in humid coastal regions.

International screening nurseries, in which large numbers of lines are rated mainly for disease resistance in many locations around the world, identify early generation lines that have strong resistance. Breeders then can use these lines as sources of resistance to improve other lines.

Durums from the USA are being used as sources of good stem

rust resistance. The drawbacks of U.S. durums are their tallness and their susceptibility to stripe rust. They have good pasta-making quality.

Although durum lines are screened for leaf and stem rust resistance at Ciudad Obregon, rust races at this location are more virulent on the bread wheats than on durums. Therefore rust data are also collected in northeastern Mexico where rusts, mainly leaf rust, cause a severe infection in the durums so resistant cultivars can be identified. Durums are also tested along with bread wheats at Patzcuaro, Mexico, for septoria resistance. A high level of natural infection occurs at Patzcuaro. Although 90 percent of the bread wheats had adequate resistance there, only 10 percent of the durums showed good resistance.

**Better yield
potential**

Cocorit, a Mexican release in 1971, has been until now the standard for a high-yielding, widely adapted durum. It has been so

Two former CIMMYT trainees, G. Gebeyehou of Ethiopia, left, and M. Bouchoutrouch of Morocco meet at a regional wheat workshop in Tunisia.



successful that farmers in California and Arizona, USA have been buying a large share of the Mexican crop of Cocorit seed. But the line Stork "S", released by Mexico in 1975 under the name Mexicali, is setting a new standard. In the 6th International Durum Yield Nursery, Mexicali outyielded Cocorit at 12 of the 28 reporting locations and it showed similar yield to Cocorit 71 in another four locations. A large portion of its yield advantage over Cocorit can be attributed to Mexicali's lower degree of sterility and larger seed. Mexicali has, in addition, markedly better grain quality than Cocorit and other Mexican durum varieties.

Mexicali's yield pre eminence is likely to be short-lived however. In the 1975 harvest at Ciudad Obregon, breeders found 47 lines that yielded more than Mexicali. Since those lines included several crosses of Mexican types with U.S. and Chilean durums, their grain quality and disease resistance are likely to be good.

Cold tolerance Durum growing extends into higher elevations in such countries as Turkey, Algeria, and Chile. Two types of cold tolerant durums are needed for higher elevations and for durum areas far from the equator. True winter durums, types that require vernalization (exposure to a cold period) to induce flowering, are needed in some areas. Other areas need varieties that can do well through short cold spells during the growing season.

CIMMYT breeders have assembled seed from the world durum collection and from national programs which are believed to carry cold tolerance. They will use them to transfer greater cold tolerance to spring durums.

CIMMYT breeders are also turning to the bread wheats where winter growth habit is more pronounced than in durums. The breeders are using winter bread wheats and the progeny of spring x winter bread wheat crosses as parents. Crossing bread wheats and durums, however, brings with it new sterility problems.

Drought tolerance CIMMYT is screening many lines including tall durums to find accelerated maturity. Such durums should combine a long vegetative period, which would allow them to flower after the danger of late spring frost is past, with a rapid grain filling stage before the onset of extreme summer heat. Crosses are made with high yielding dwarf durums and the progeny are sent to the Mediterranean region to test for the presence of accelerated maturity and to measure yield.

CIMMYT breeders are also using as parents several tall durums that have ability to withstand dry spells. Crosses have been made with high yielding dwarf durums and the F₂ segregating populations are

being selected by cooperating breeders at several locations for drought resistance, short height, and good grain quality. The lines selected are then used as parents in subsequent crosses.

Better grain quality

Durum grain is rated by CIMMYT breeders for kernel size, shape, and density. The CIMMYT milling and baking laboratory rates the grains of all lines for pigmentation and evaluates macaroni made from grain of advanced lines.

One failing of current high-yielding durums is their tendency to have floury endosperm in a portion of the kernel, instead of endosperm which is entirely vitreous. The mottled appearance of a kernel with some floury endosperm is called "yellow berry." This is undesirable in the market. The amount of yellow berry tends to increase in durums grown in soils that have low nitrogen fertility. Mexicali 75 has less yellow berry than Cocorit, and many advanced lines have even less yellow berry than Mexicali.

Pigment (yellow color measured by carotinoid content) is a preferred characteristic for pasta. But high content of lipoxidase, an enzyme, can break down carotinoids. For example, evaluations made in 1975 showed that the variety Haurani from Syria has a high pigment content in the grain, 7.9 ppm, but the color of macaroni made from it rates only 4 on a 0 to 9 scale. A CIMMYT line called Cormorant "S" has moderate pigment content, 3.5 ppm, but its macaroni color rates 7. Gediz, a variety selected and released in Turkey from a CIMMYT cross, has both a high grain pigment content, and apparently, a low lipoxidase content. It has 6.7 ppm pigment and its macaroni color rates 9. CIMMYT breeders are using Gediz to improve the quality of newer lines. Varieties from the USA and Italy are also being used as sources of better pasta-making quality.

Crossing durums with bread wheats

A decade ago the Norin-10 dwarfing gene was introduced into durums by crossing dwarf bread wheats with durums. Now CIMMYT durum breeders are turning once again to bread wheats for certain desirable characteristics which bread wheat germ plasm has in greater abundance than durum germ plasm. Disease resistance is one. In 1975 the breeders chose numerous spring wheats for their resistance to septoria and rust and made 250 crosses with durums.

The difficulty in this technique is that many bread wheats are incompatible with durums. Half of the 250 crosses set no seed. Thirty of the bread wheat parents crossed satisfactorily with durums but the progeny still must be recrossed with durums to improve fertility.

Cold tolerance and winter growth habit are not widely found



Mohan Kohli, triticales breeder, right, shows new rust-resistant lines to Glenn Anderson.

in durum germ plasm. CIMMYT breeders are using the F₁ progeny of spring x winter bread wheat crosses to cross with durums in hopes of increasing the cold tolerance of durums.

The most advanced material in this program was in the F₃ generation in 1975. Lines with good plant type, disease resistance, and high fertility are showing up. Several hundred crosses between spring bread wheat and durums, and between F₁ spring x winter bread wheats and durums were made in 1975.

**International
nurseries**

Seven different types of durum nurseries were sent to a total of 47 nations in 1975. The largest nurseries were the International Durum Screening Nursery which was sent to 68 locations and the International Durum Yield Nursery which was sent to 66 locations.

TRITICALE

A century ago, a British scientists crossed a wheat plant and a rye plant, producing a progeny wheat x rye plant which was sterile. The first triticale—fertile wheat x rye cross—was produced in Germany in the late 1880's, but triticale remained an academic curiosity until the mid-Twentieth century when biochemical techniques were developed that increased the probability of getting fertile triticale plants from wheat x rye crosses. Improvement of triticale as a crop began in Hungary about 1947; other researchers in Europe and in North America soon followed. When CIMMYT was founded in 1966 it continued a cooperative triticale project which had been established a few years earlier between the University of Manitoba (Canada) and the Rockefeller Foundation program in Mexico.

The first triticales were tall, very late maturing, and had a high degree of sterility. Since then methods of creating new triticales have vastly improved. Large numbers of triticales have been crossed with each other and to wheats to concentrate desirable genes, and the best progeny have been carefully selected and tested. Today the best triticales can compete in yield with the best wheats. While not without problems, triticales show some strengths over other cereals. Triticales are nearing the point where they can be a serious alternative for many of the world's farmers and in three countries--Hungary, Spain, and the USA--there are already sizeable plantings.

**New primary
triticales**

In the last 5 years, techniques for crossing wheat plants with rye plants to create new triticales have vastly improved and the germ plasm base with which breeders are working has expanded dramatically. A new primary triticale is created by fertilizing a wheat plant with pollen from a rye plant. A few weeks later the embryo is surgically removed and placed in a nutrient medium where it grows into a plantlet. The plantlet is transplanted into a pot with soil and at the appropriate time it is bathed in the chemical colchicine to double the number of chromosomes in each cell. Removing the embryo from the seed is necessary because the endosperm of the seed usually is unable to support germination and growth. The chromosomes of the plantlet must be doubled to allow cell division in the reproduc-

tive organs to proceed normally, consequently making the plant fertile.

Crossing a durum wheat (four sets of chromosomes) with a rye (two sets of chromosomes) gives a hexaploid triticales (six sets of chromosomes). Crossing a bread wheat (six sets of chromosomes) with a rye gives an octoploid triticales (eight sets of chromosomes). Since 1973 the number of primary triticales created has doubled each year.

Primary triticales usually are crossed with each other to produce secondary triticales or they are crossed with secondary triticales to produce other secondary triticales. Octoploid triticales (from bread wheat x rye) are less fertile and less vigorous than hexaploid triticales (from durum x rye). But by crossing hexaploid with octoploid triticales, one or more sets of the bread wheat chromosomes can be moved from the octoploid triticales into hexaploid triticales. Nearly all advanced triticales lines are now hexaploid but most have been crossed at some stage with an octoploid triticales. Thus the best characteristics from bread wheats have been introduced into hexaploid triticales.

Triticales products In 1968 kernels of triticales yielded only 50 percent flour because of poorly developed seed, compared with 70 percent for bread wheat. In 1975 triticales tested at CIMMYT had a flour yield of 53 to 69 percent. Baking tests are being conducted with triticales flours and mixtures of triticales and bread wheat flours. Some triticales lines provide flour that is better for hard rolls (*bolillos*) and cookies than the soft bread wheats. When triticales flour is used to make chapatis, they keep moist longer than those made from bread wheat flour.

Winter x spring crosses The weather pattern at CIMMYT's Toluca experiment station allows winter-growth-habit cereals planted in November to flower at the same time as spring-growth-habit cereals planted in January. Thus crosses of winter triticales x spring triticales, winter rye x spring wheat, winter wheat x spring rye, and winter wheat x spring triticales can be made in the field on a large scale. Since winter ryes have been improved much more than spring ryes in the world's breeding programs, access to this pool of germ plasm greatly increases the variability in the rye component in new triticales. Among the benefits of such crosses are earlier maturity and better cold tolerance in spring triticales. At the same time, triticales with winter growth habit are being produced. The first test of winter triticales was conducted in Ontario, Canada, in the winter of 1974/75. Ninety percent of the planting was killed by cold and most of the survivors were very poor types. But one plant in ten of the surviving triticales looked as

good as spring triticales grown in Mexico. These are the parent stock for continuing improvement.

Wider adaptation One penalty of the narrow germ plasm of early triticales was their lack of adaptability. That is, when tested at many locations throughout the world they were unable to give consistently high yields. In the First International Triticale Nursery in 1969-70 the yields of the best triticale varieties were only 75 percent of the yield of Pitic, a widely adapted dwarf bread wheat. Since then triticales have progressed and in the fifth nursery (1973-74) they outyielded wheat check varieties internationally. A steady upward trend in adaptation has thus been observed.

New rye parents Since 1972 CIMMYT breeders have assembled a world collection of rye which includes 500 varieties. In addition CIMMYT scientists have collected land races (native ryes) in Turkey to increase the germ plasm available for creating new triticales. A short rye called Snoopy was used extensively to reduce the height of triticales. In addition to being short, the progeny of Snoopy are early maturing but tend to be susceptible to diseases and they have small spikes (grain heads). CIMMYT breeders crossed Snoopy with tall, late ryes to get short, early, long-headed ryes which are now being used as parents for new triticales.

A reunion in the Ciudad Obregon experimental fields between Willie McCusiston, right, former CIMMYT staff member currently with Oregon State University and, from left, Jesse Dubin, Mohan Kohli, and Sanjaya Rajaram.



Better disease resistance	<p>Triticale shows good resistance to serious diseases of wheat. But most triticales do not have adequate resistance to such diseases as ergot and head blight (<i>Fusarium</i> spp). To identify sources of resistance, triticale screening nurseries were sent to 90 locations in 1975. These nurseries will also provide information on diseases that might become important once triticale is grown widely as a crop.</p> <p>The rapidly increasing number of new primary triticales which are being created has greatly expanded the amount of genetic variability for disease resistance in triticales.</p>
Better protein	<p>Early triticales had an extraordinarily high percentage of protein because the shrivelled grains had a low starch content. As the plumpness of triticale grains has improved the protein percentage has predictably fallen. Grains of high yielding triticales now have 10.5 to 13.5 percent protein, which compares with 10 to 12 percent protein in bread wheats grown in the same fields. Protein quality is generally measured by the percentage of lysine, which is the first limiting amino acid. Advanced lines of triticale in 1975 had 3.2 to 4.2 percent lysine compared with 2.3 to 3.0 percent for bread wheats. Thus under Mexican climatic conditions triticales produce total protein which is at least 10 percent higher than that of bread wheats, and the lysine content is generally 50 percent higher than that of bread wheats.</p>
Triticale's future	<p>CIMMYT scientists believe that a new crop like triticale must earn its place in farmers' fields and the market place. CIMMYT's role is to see that it is widely tested. Thereafter, triticale should be grown where it shows commercial advantage for bread-making, or animal-feeding, or animal-grazing, or distilling.</p>

BARLEY

Barley is a basic food in regions where the growing season is too short or the rainfall inadequate for other cereals. Substantial populations eat barley in the Mediterranean region, Mideast, India, China, Korea, the Andean Region, and Eastern and Northern Europe.

Although improved barley varieties have been developed for brewing beer and for cattle feed, varieties for human food have been virtually ignored by plant breeders. Yet barley is the staple food of millions of persons who live near the margins of the deserts and in arid high plateaus. CIMMYT's barley program began in 1972 with the aim of producing varieties that are suitable for human food and give high stable yields.

Most barleys eaten by human populations are low yielding, susceptible to disease, and narrowly adapted, that is, they perform poorly when moved away from their native area. The grains of most varieties have hulls and are useful in making beer or feeding cattle, but the hulls must be removed before the grain can be eaten by humans. Additionally, barleys for beer making have been bred for low protein content, too low to make a satisfactory staple human diet.

After 3 years of testing, CIMMYT has assembled good breeding sources of nearly all characters it wants to incorporate in barley varieties. Crosses have produced large numbers of barley lines combining several desirable characters. Some advanced barley lines now contain higher yield potential, wider adaptability, and naked (hull-less) kernels. None of these lines yet show a sufficient range of disease resistance.

- | | |
|-----------------------------------|---|
| Wider adaptation | Lack of adaptation is caused in part by sensitivity to daylength. Varieties with sensitivity flower only when a certain length of day occurs. If temperate barleys are planted in the tropical zone, they may flower too late, or not at all. CIMMYT breeders are able to eliminate daylength sensitivity by growing lines in the winter at a location at 27°N and in the summer at a location at 19°N. Since the winter location is a sea level desert and the summer location a humid plateau at 2200 m elevation, the barley lines are subjected to vastly different environments, and only those that show wide adaptation survive. |
| Greater disease resistance | Severe epidemics of the two leading barley diseases, scald (<i>Rhynchosporium secalis</i>) and powdery mildew (<i>Erysiphe graminis</i>) during 1975 allowed breeders to identify parents that have strong resistance to these diseases. Benton, a variety from the USA, has notable resistance to scald. Fifty percent of the other breeding lines were discarded because of susceptibility to these diseases.

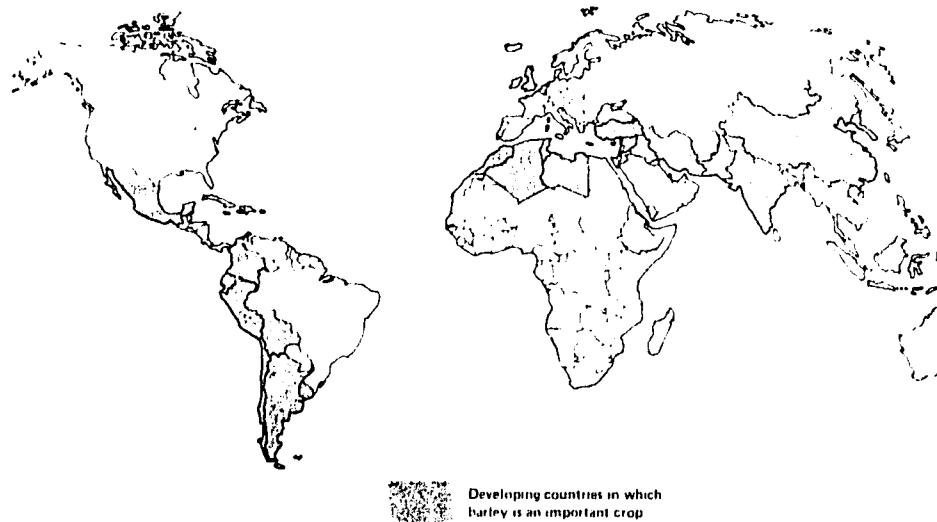
While a severe epidemic helps breeders spot good sources of resistance, it interferes with testing for other diseases. The International Barley Observation Nursery provides information on the resistance of lines to numerous diseases. The Third IBON containing 250 lines was sent to 42 locations around the world in 1975. Since the predominant disease problems tend to differ from location to location, the results of the IBON give breeders information on resistance of each line to various barley diseases. |
| Naked grains | Varieties with naked (hull-less) grains will save barley-eaters the labor of pounding or soaking barley to remove the hulls. Through crosses to Godiva, a variety from USA, and other naked types, 40 percent of the |

barley lines in early generation now have naked grains. The plumpness and size of grain in naked types still requires improvement.

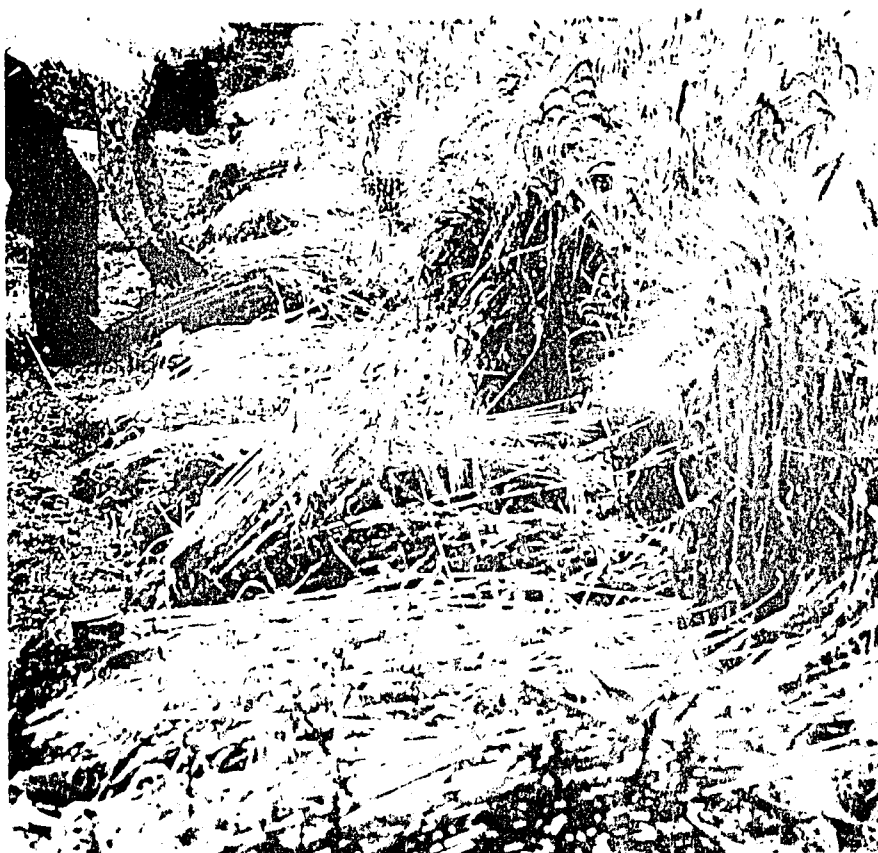
Better protein CIMMYT breeders aim to raise the quality of barley protein. Protein quality can be improved by increasing the amount of lysine, an essential amino acid.

About 40 percent of early generation lines now have one or two sources of improved protein quality in their parentage. The Hiproly variety, one of the sources, has a high protein content and a gene for high lysine content. Riso Mutant 1508, the other source, is an induced mutant with about the same protein content as Hiproly and about 15 percent higher lysine. Unfortunately, both varieties cause shrivelled grain in their progeny. And attempts to improve the plumpness of the grain lead to lowered lysine content, especially in progeny of Riso Mutant 1508. Since the linkage between lysine content and shrivelled grain is less difficult to break in Hiproly progeny, the program emphasis is shifting to Hiproly as a source of better protein. Some progenies of crosses with Hiproly have up to 3.5 percent lysine which is less than that of Hiproly itself, but still well above the average for barley. To eliminate shrivelling breeders are crossing the lines with Egyptian barleys that have heavy plump grains.

Earliness In many areas, barley is the only cereal that matures quickly enough to produce grain in a brief rainy season or in a short frost free summer. Super Precoz, a line from USSR, flowers in 40 days and can be harvested in 70 days at Mexico's latitude. Like most very early lines it has low yield and other deficiencies such as a tendency to lodge and



The best barley plants are pulled and arranged in rows for close inspection and selection.



susceptibility to disease. Nearly 100 other lines, while not as early maturing as Super Precoz, are 15 to 20 days earlier than any commercial variety and they have less lodging and better disease resistance. These lines will be yield tested in 1976.

High quantity of protein, and naked hulls, have not yet been combined in the same variety with early maturity.

Stronger straw

Among the chief reasons that traditional barleys yield poorly is their tendency to lodge (fall over) before harvest. Most barleys are tall, have weak stems, and weak root structures.

CIMMYT breeders have crossed a short Indian mutant with taller varieties to improve this agronomic feature. The progeny themselves are too short to be used as varieties by farmers, especially those who use no fertilizer and who do not control weeds. Instead the short progeny are being used as parents to reduce the height of other tall barleys.

Some varieties from Japan and the USA are sources of strong stems; Mexican barleys are providing sturdy roots.

Higher yield potential In 1975 the barley program reached the stage where the first advanced barley lines could be yield tested. Trials at Ciudad Obregon showed that under optimum conditions (irrigation and no disease) 10 percent of the barley lines were capable of equalling or exceeding the yield of the durum and bread wheat check varieties. Moreover, the barley yields were achieved on one less irrigation than was necessary for the wheat varieties.

Twenty-five barley lines that showed high yield potential in Mexico were assembled into sets and sent to 32 locations in barley growing countries as the First International Barley Yield Nursery. These were shipped in the spring of 1975 for fall planting, and data should be returned in 1976.

New crossing technique A bottleneck in any cereal improvement program is the number of crosses that can be completed in the brief time that the crop is in flower. In barley the flowers are set deep in the leaf sheath making it difficult for the breeders to remove the male organs. The breeders tested a new emasculation technique in 1974 and used it on a large scale in 1975. They cut away the leaf sheath surrounding the inflorescence (flowers) which exposes the anthers and makes them easier to remove. The technique allows the breeders to do 800 emasculations a day with fewer workers than were needed to do 300 a day in previous years. An additional advantage of the technique is that when it is properly done the ovaries are more receptive to fertilization, so more seeds are set.

International testing The yield potential, disease resistance, and general performance of 25 advanced CIMMYT barley lines are being tested in replicated trials at 32 locations around the world in 1975-76. This is CIMMYT's first international barley yield nursery.

In addition sets of 250 barley lines were sent to 42 locations as the Third International Barley Observation Nursery. This unreplicated nursery will provide readings on the insect and disease resistance of the lines for scientists in national programs and at CIMMYT.

DEVELOPMENT OF NEW GERM PLASM

For several years CIMMYT has been developing unconventional germ plasm which can be used as donor parents for future crosses in bread wheats, durum wheats, and triticale. The progress of this work can suggest the nature of new varieties which may emerge over the next 5 to 10 years.

Special desirable characteristics are being refined and "pyramided," for subsequent transfer into well adapted, high-yielding, disease resistant lines.

New sources of dwarfing Most semi-dwarf varieties of bread wheat get their dwarfing genes from Norin-10. Two later varieties in the breeding program, S948A1 and Tom Thumb, have different dwarfing genes than Norin-10. By 1974 CIMMYT had produced uniform lines involving these new sources of dwarfing which were then grown in yield trials harvested in 1975.

One trial consisted of lines similar to CIANO F67 but carrying the two new dwarfing genes. The lines produced higher yields, more stems and more spikes per square meter than CIANO F67, and 19 out of 21 progeny had more grains per spike. Maturity was equal. A second trial consisted of a number of lines similar to INIA 66 but carrying the new dwarfing genes. These lines yielded more than INIA 66 and equalled the yield of Jupateco 73. In a third trial nine lines derived from crosses between Santa Elena and S948A1 outyielded Jupateco 73, Super X, Torim 73, and Yecora 70, four of the highest yielding commercial varieties in Mexico.

In general these trials showed that within certain limits it is possible to increase yield of a number of the older and taller varieties by shortening the plant. Thus additional genes may be used to obtain still higher yields if they are incorporated into the presently available dwarf varieties.

Branched spikes In most wheats, spikelets are arranged along a central axis called the rachis. By contrast, some wheats have a branched rachis which makes room for more spikelets. This in turn means that a branched spike might produce more grains than normal.

Since 1970 branched wheats at CIMMYT have been improved in fertility, grain plumpness, more vigorous tillering, stronger stems, and greater disease resistance. In 1975 one branched-spike of bread wheat M. Reo x I18156 (R)4 outproduced Super X and Jupateco 73, two bread wheats and was equal to the two durum varieties Stork (S) and Cocorit.

Protein improvement In 1974 using 11 lines or varieties of wheat which had been identified as having higher protein quantity, or higher protein quality, or both, CIMMYT initiated a crossing program to transfer these characters from poor plant types into more desirable genotypes with higher yields.

A trial of 34 lines in 1975 produced yields of 5600 to 8900 kg/ha combined with protein ranging from 15.3 to 18.6 percent of grain

weight. The check variety CIANO F67 had 14.8 percent protein as a check. Tests for protein quality (dye-binding capacity) show normal or better quality of protein than the check variety. CIMMYT breeders conclude that it is reasonable to expect a substantial increase in protein by this approach, with the possibility of improving protein quality as well.

WIDE CROSSES

Progress with triticale (rye and wheat) has prompted CIMMYT to investigate the possibility of creating other "wide" crosses between genera, such as wheat, barley, oats, and rye.

In 1975, several crosses involving barley and durum wheat or bread wheat were successful. The barley was pollinated with wheat pollen. Seed set occurred without the use of chemical treatment. The hybrid seed, however, was small and lacked a normal endosperm. The seed embryos, which were small and badly formed, were excised from the seed and placed in a special nutrient agar medium. Seven of the embryos developed into hybrid wheat-barley plantlets.

The hybrids between barley (14 chromosomes) and durum (28 chromosomes) had the expected 21 chromosomes and the hybrids between barley and bread wheat (42 chromosomes) had the expected 28 chromosomes. None of the hybrids showed signs that chromosomes were being eliminated—a common problem in intergeneric crosses.

The hybrid plants strongly resemble wheat in their general growth habit, in the appearance of the spike, and in resistance to powdery mildew of barley. Because the plants are haploid (having single chromosomes instead of paired chromosomes), they are sterile. Cytologists plan to use colchicine to double the number of chromosomes, as is routinely done with triticale haploids.

Much preliminary knowledge of chromosome behavior is needed before this work can approach a usable product. CIMMYT expects to continue its work on a modest scale, to evaluate the work every few years, and to encourage basic research institutions to engage in similar investigations.

PHYSIOLOGY

Yield in optimum environment	CIMMYT's wheat station at Obregon experienced cooler-than-normal weather in 1975, especially in April, which prolonged the growing
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season and raised yields of several wheats over 9000 kg/ha. For example, in optimum management trials Yecora, a three-gene dwarf, yielded 9070 kg/ha. In comparable trials conducted during the previous 4 years Yecora yielded 6410 to 7950 kg/ha. Thus in the absence of disease and with no lack of water, small differences in mean temperatures and solar radiation can cause yields to differ by up to 35 percent.

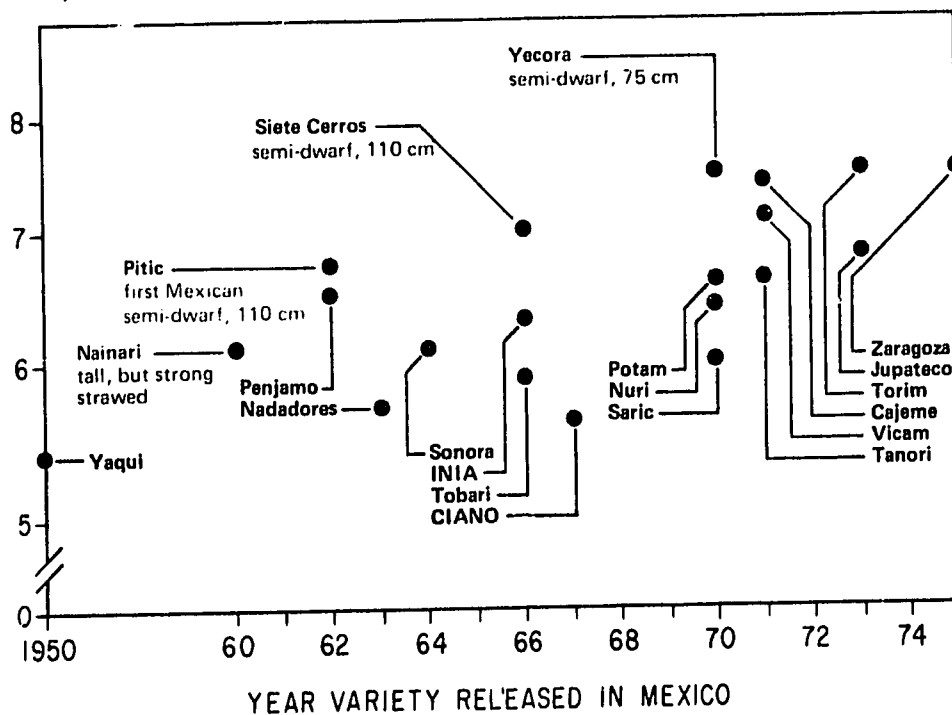
Eight out of 48 lines in the optimum-management trials yielded over 9000 kg/ha. Five of the eight lines were bread wheats and three were durum.

Selecting plants in early generations

In early generations only a handful of seeds exists for each cross. To make visual selection easier and to maximize the increase of seed, early generations are planted at abnormally wide spacings. While plants can be discarded for poor plant type, weak disease resistance, etc., yield potential cannot be assessed until later generations when enough seed exists for replicated trials.

Pushing back the yield barrier: Average yield of Mexican varieties under optimum management and in the absence of disease (Physiology trials at Ciudad Obregon, Mexico).

Yield, t/ha (ratio scale)



Physiologists have been looking for a simple way to predict yield potential on the basis of single plants. In 1974 and 1975 they tested dozens of genotypes in spaced plantings and large plots to compare measures such as grain weight, grain number, spikelets per spike, and harvest index (ratio of the weight of the grain to weight of the entire plant). Harvest index of widely spaced plants was consistently the most reliable indicator of yield of normally spaced plants in large plots.

If harvest index proves successful in predicting yield when measured in segregating populations, physiologists believe that its use may permit breeders to reduce the number of lines that are carried to later generations where a large proportion are rejected for inadequate yield. Moreover, use of harvest index might reduce chances of eliminating early-generation plants that have a high yield potential.

In the arid environment of northwest Mexico the plants do not have to be oven-dried to get a reasonably accurate estimate of harvest index. Nevertheless, measuring harvest index on a plant might take twice as long as mere visual selection. It remains to be seen whether the benefits of using harvest index outweigh the reduced number of plants that can be selected in a day.

Plot size In yield trials competition between different genotypes in adjacent plots can bias the results. Physiologists compared standard four-row plots, where all rows were harvested, with five-row plots, where only the three center rows were harvested after the plot ends had been removed. They found that four-row plots bias yields in favor of tall genotypes. Most of the bias results from competition for light from the outer rows of adjacent plots.

Yield potential in three crops One outstanding variety of bread wheat, of durum wheat, and of triticale were compared under optimum conditions (irrigated, well-fertilized, no disease problems) as part of a continuing study to identify barriers to higher yields. For the first time durum, represented by Mexicali 75, a new variety, appeared as the highest yielding and most efficient genotype. Mexicali has a very high harvest index and large kernels. Its tillering and leaf area index are below average (leaf area index is the ratio of total crop leaf area to the area of land occupied). The bread wheat variety Yecora yields almost as well as Mexicali by producing many more grains per square meter although the grains are substantially lighter.

Erect leaves In 1975, physiologists began to test the idea that wheat plants with erect leaves might be more efficient photosynthetically than plants

with the usual droopy leaves. Yield trials of related spring wheat populations bred specifically to have leaves at varying degrees of erectness showed a statistically significant relationship between higher yield and more erect leaves in some populations, primarily because the number of grains per square meter increased. On the other hand, erect leaves were also associated with somewhat lower kernel weight. In durums, erect leaves were similarly associated with lower kernel weight, but grains per square meter did not increase, so yields fell.

More studies will be needed to determine whether these responses reflect underlying physiological effects of erect leaves or whether they are unique to the particular lines used in these experiments.

**Shade and
yield potential**

Studies with 12 wheats in 1975 confirmed earlier studies, done previously on one variety, that the amount of sunlight a plant receives is most critical in the 30 days before and after flowering. If solar radiation is low (for example if the weather is cloudy) in the 30 days before flowering, fewer than the normal number of grains are formed and yield is reduced. If solar radiation is low in the 30 days after flowering, a reduction in kernel size reduces yields in cool seasons. In general these results point to grain number as the key to higher yields; and to solar radiation in the month before flowering as the key to grain number.

Drought resistance

In a trial involving 54 bread wheats, durums, triticales, and barleys, the mean yield of short bread wheats and short durums under drought stress was equal to the mean yield of tall bread wheats and barleys about 2500 kg/ha. In control plots (with adequate irrigation), yields ranged from 5000 kg/ha (tall bread wheats) to 7000 kg/ha (short durums).

The early maturity of barleys is an advantage under drought. In effect, because they ripen sooner than wheats, barleys do not have to endure drought for as long. Moreover, barley yields include the weight of the hulls, so the actual grain yields of barley under drought stress are perhaps 5 to 10 percent lower than the yields of bread wheats and the short durums.

The experiment again provided evidence that all wheats do not necessarily perform better under drought than short wheats. The mean yield of the 11 dwarfs, 100 to 110 cm tall (measured under well-watered conditions), was 2600 kg/ha, the yield of the nine dwarfs, 90 to 100 cm tall, was 2570 kg/ha, while the yield of the eight tall wheats (averaging 120 cm tall) was 2520 kg/ha. Under drought, the

inherent productivity of short wheats is not completely erased, so their yields match those of the tall wheats even though some tall wheats may have genes for drought resistance.

Wheat growth in hot, humid climates

Many nations in the hot humid tropics import large amounts of wheat. Several are interested in reducing their imports by growing wheat in their relatively cool, dry, winter season. Most wheats do not grow well because of physiological disorders in addition to severe insect and disease problems.

In 1975 physiologists continued studies of the adaptability of spring wheats and triticales at four locations in Mexico which range from hot and humid to cool and dry. Temperature is the chief physiological reason for low yields in a hot climate, but there were indications that if solar radiation levels are high, the deleterious effect of high temperature is not as great. Several triticales performed surprisingly well at the hot, humid location.

AGRONOMY

Trials in farmers' fields in an irrigated desert

Five triticales were compared with Mexicali 75, a new durum variety, and Jupateco 73, a bread wheat variety, in five farmers' fields in the irrigated Yaqui Valley of northwest Mexico. The trials were grown with the farmers' cultural practices which are equal to those of the best farmers in the world. Jupateco 73, the bread wheat variety grown by most farmers in the area, yielded 6900 kg/ha and Mexicali 75 yielded 6800 kg/ha. The best triticales were a line called Bacum, 6000 kg/ha, and the variety Yoreme, 6300 kg/ha. The slight difference in yield of the triticales in comparison with the bread wheat and durum varieties indicates the rapid progress that has been made in triticales breeding in less than a decade, as well as the magnitude of the job that lies ahead.

A rainfed high plateau

Barley is the traditional small grain grown in the cool, arid areas near Cuernavaca, CIMMYT's headquarters on Mexico's high plateau. Five triticales were compared with a bread wheat and a barley variety, in six farmers' fields. The trials were conducted by CIMMYT trainees in collaboration with the Mexican extension service.

Several triticales entries yielded over 4000 kg/ha at some locations reflecting a good growing season, the application of fertilizer, and the control of weeds with herbicide. At five locations, Cleopatra, a bread wheat developed by INIA, the Mexican research service, for dryland areas, had the highest average yield, 3500 kg/ha. Barun, was



A trainee gets detailed advice on rating rust infection from Santiago Fuentes, wheat pathologist, left.

Nitrogen sources

the highest yielding triticale, averaging 3200 kg/ha. The barley variety yielded 2700 kg/ha. Although presently available triticales offer a better yield potential than barley, they are more risky in this area because their longer maturity makes them vulnerable to early frosts.

In two sets of trials at Ciudad Obregon, sulfur-coated urea, a fertilizer that releases nitrogen slowly, showed no advantage. In one trial, yields with sulfur-coated urea were 1000 kg/ha lower than yields from conventional fertilizers such as ammonium sulfate and

Bread wheat, durum, triticale, and barley nurseries distributed by the International Nurseries Program, 1975.

Country	Bread wheat	Durum	Triti- cale	Barley	Country	Bread wheat	Durum	Triti- cale	Barley
<i>North America</i>	46	16	41	3	Switzerland	1	—	3	—
Canada	12	3	16	2	Yugoslavia	7	3	3	2
USA	34	13	25	1	<i>Africa</i>	102	54	60	26
<i>Latin America</i>	118	46	71	30	Algeria	12	13	10	5
Argentina	22	23	13	3	Cameroon	3	1	2	1
Bolivia	4	—	13	3	Chad	2	1	—	—
Brazil	24	4	13	1	Egypt	10	4	2	3
Chile	10	5	9	4	Ethiopia	10	8	11	1
Colombia	2	—	2	—	Ghana	2	—	1	—
Costa Rica	1	—	1	—	Kenya	5	9	6	2
Cuba	1	—	1	—	Lesotho	1	—	1	—
Ecuador	6	2	4	4	Malagasy	1	—	—	—
Guatemala	7	—	3	1	Malawi	2	—	—	—
Guyana	1	—	—	—	Mali	1	1	—	—
Honduras	2	—	1	—	Morocco	1	1	1	1
Mexico	16	9	8	9	Nigeria	5	3	2	2
Nicaragua	3	—	3	—	Rhodesia	4	1	5	1
Paraguay	5	—	2	1	Senegal	2	—	2	—
Peru	9	3	7	3	Somalia	4	2	2	2
Uruguay	3	—	1	—	South Africa	14	3	5	4
Venezuela	2	—	1	—	Sudan	6	—	3	—
<i>Europe</i>	55	47	64	19	Tanzania	4	—	2	—
Albania	—	3	1	—	Tunisia	8	7	2	4
Austria	1	3	—	—	Uganda	1	—	—	—
Bulgaria	1	—	2	—	Zaire	2	—	1	—
Czechoslovakia	1	—	1	—	Zambia	2	—	2	—
Denmark	—	—	—	4	<i>Middle East</i>	57	57	23	22
England	5	1	3	2	Cyprus	5	4	1	1
Finland	1	—	1	—	Iran	8	—	3	2
France	3	11	7	—	Iraq	8	7	1	3
W. Germany	3	1	1	2	Israel	5	3	2	—
Greece	2	2	2	—	Jordan	4	8	4	3
Hungary	3	—	5	2	Lebanon	9	9	6	4
Ireland	1	—	1	—	Libya	2	4	1	1
Italy	1	9	—	—	Saudi Arabia	1	2	—	1
Malta	1	1	—	—	Syria	4	6	3	2
Netherlands	4	1	3	1	Turkey	9	10	2	3
Norway	—	—	1	—	N. Yemen	1	2	—	1
Poland	4	5	5	—	S. Yemen	1	2	—	1
Portugal	1	—	2	—	<i>East Asia and</i>				
Rumania	5	1	4	—	<i>Oceania</i>	133	33	79	26
Russia	5	4	5	—	Afghanistan	7	1	2	1
Spain	5	2	9	6	Bangladesh	6	—	4	3
Sweden	—	—	5	—	China	19	2	5	2

continued

Bread wheat, durum, triticale, and barley nurseries distributed by the International Nurseries Program, 1975, *continued*.

Country	Bread wheat	Durum	Triti-cale	Barley	Country	Bread wheat	Durum	Triti-cale	Barley
India	41	17	35	6	Pakistan	27	9	19	7
Indonesia	1	—	—	—	Thailand	1	1	1	—
Japan	3	—	1	1	Australia	12	1	5	1
S. Korea	6	—	3	4	New Zealand	2	2	—	—
Nepal	8	—	4	1	Total	511	253	339	126

ammonium nitrate applied before sowing. In another trial in which the time of application in relation to sowing was varied, yields with sulfur-coated urea were no better than those from other nitrogen sources.

INTERNATIONAL TRIALS

In 1975 collaborating scientists in 90 nations planted over 1200 trials of wheat, triticale, and barley nurseries distributed by CIMMYT. A nursery consists of a set of varieties or lines, some times as many as 300. Identical sets are sent to scientists in numerous locations. The results reveal the adaptability of each entry to dozens of different ecological conditions as well as the breadth of disease resistance of the entry. The information derived from 1 year of testing at so many locations could not be equalled by decades of testing at one location.

CIMMYT's international testing program has grown from cooperative wheat testing organized in North and South America in the late 1950's. When the Rockefeller Foundation program in Mexico received its first trainees from outside of the Americas in the early 1960's the idea of world-wide tests developed. The First International Spring Wheat Yield Nursery in 1964-65 was the beginning. Other types of nurseries have followed. Nurseries are sent out annually in triticales, durums and barleys as well as bread wheats. Some nurseries consist of F₂ seed, others contain released varieties, still others have seed of generations between F₂ and released varieties. Certain nurseries are replicated, other are not.

The nurseries are also a mechanism for distributing germ plasm. Any entry in any nursery can be used as the local breeder sees fit. He may use an entry as a parent for making crosses with local varieties,

or make selections from the entry, or multiply the entry for direct release to farmers

A not insignificant benefit of the nurseries is that they foster contact and cooperation among scientists in nations with wide social and political differences

In 1975, 90 countries received nurseries. The total weight of the nurseries, shipped by air, was 3500 kilograms

Number of entries per nursery and distribution of each nursery, 1975.

Nursery	Entries per nursery	Sets distributed (no.)				Middle East	East Asia and Oceania
		North America	Latin America	Europe	Africa		
<i>Bread Wheat</i>							
Crossing block	239	3	6	1	3	5	11
F ₂ irrigated	482	1	10	2	6	8	17
F ₂ dryland	480	4	16	3	9	3	13
F ₂ spring x winter	394	7	16	7	10	7	21
Int. Bread Wheat Screening	386	8	36	15	37	16	36
Int. Spring Wheat Yield	50	14	20	18	22	11	22
Multiline	215	1	2	4	7	4	9
Int. Septoria Observation	213	7	12	5	8	2	3
F ₁	756	1	0	-	-	1	1
<i>Durum</i>							
Crossing block	128	1	3	1	1	6	4
F ₂ irrigated	89	2	10	9	8	11	4
F ₂ dryland	76	2	4	6	7	15	3
Int. Durum Screening	289	2	12	12	16	12	11
Int. Durum Yield	25	7	12	15	13	5	7
Elite Durum Yield	25	1	5	4	7	6	3
F ₁		1	-	-	2	2	1
<i>Triticale</i>							
Crossing block	264	2	2	-	2	1	3
F ₂ irrigated	204	6	9	6	5	3	12
F ₂ dryland	425	8	8	9	6	2	12
F ₂ spring x winter	82	9	6	12	3	1	10
Int. Triticale Screening	300	4	31	21	24	10	22
Int. Triticale, Yield	25	11	12	15	18	6	19
Triticale Disease Resistance	102	1	3	1	2	-	1
<i>Barley</i>							
Crossing block	361	1	5	7	5	6	5
F ₂	202	1	8	5	5	3	6
Int. Barley Observation	250	-	11	5	9	8	8
Exp. Barley Yield	25	1	6	2	7	5	7
Total		106	265	185	242	159	271

WHEAT TRAINING

Forty-six young wheat scientists from 22 countries were trained in Mexico during 1975. Since 1960, 364 wheat scientists have received in-service training.

The training programs, which last 3 to 9 months, are designed to develop ability in field and laboratory techniques, give experience in working on an interdisciplinary research team, and increase understanding of agricultural development in relation to wheat production.

The production training course was shifted from irrigated fields in the winter season at Ciudad Obregon, to rainfed fields in the summer near El Batan. Greater emphasis was placed on teaching the trainees the development of a package of practices in farmer fields.

Three issues of *Wheat Team Field Notes* were distributed to former

Wheat in-service trainees 1960-75.

Region and country	1975	1960-75	Region and country	1975	1960-75
<i>North Africa and Mideast</i>	13	181	Nepal	2	5
Afghanistan	0	18	Pakistan	1	33
Algeria	5	32	Philippines	0	1
Cyprus	0	2	<i>Latin America</i>	11	74
Egypt	1	9	Argentina	0	18
Iran	1	12	Bolivia	0	2
Iraq	0	7	Brazil	0	15
Jordan	1	6	Chile	4	9
Lebanon	1	5	Colombia	0	3
Morocco	0	17	Dominican Rep	1	1
Saudi Arabia	1	2	Ecuador	4	11
Syria	0	5	Guatemala	0	4
Tunisia	1	21	Mexico	1	1
Turkey	2	35	Paraguay	0	2
Yemen	0	3	Peru	1	6
<i>Tropical Africa</i>	10	33	Uruguay	0	2
Ethiopia	1	8	<i>Other</i>	3	15
Kenya	2	5	France	1	1
Madagascar	0	1	Hungary	0	1
Nigeria	7	11	Poland	0	2
Somalia	0	1	Portugal	0	1
Sudan	0	4	Rumania	0	2
Tanzania	0	3	Spain	0	2
<i>South and East Asia</i>	8	61	USSR	0	3
Bangladesh	3	11	USA	2	3
India	2	6			
Korea	0	5	Total	46	364

trainees during 1975. The newsletter gives news of research in national programs and at CIMMYT.

CIMMYT has six postdoctoral fellows serving as staff associates (from Ecuador, Germany, Mexico, Rhodesia, UK, USA).

Numerous visiting scientists from developing countries spent from 1 week to several months at CIMMYT during 1975.

MILLING AND BAKING LABORATORY

In the milling and baking laboratory, scientists evaluate the grain of bread wheat, durum, and triticale lines for their suitability in making products such as bread, tortillas, chapatis, cookies, and macaroni. These tests help breeders select lines that have good industrial quality.

In 1975 the laboratory tested 30,000 samples from early (F₃ and F₄) generation bread wheat lines for gluten strength and seed type. Later generation lines that have high yield and high test weight (weight of the grain per unit volume) are classified for end uses such as bread, cookies, etc.

The bread making quality of CIMMYT's wheats would be improved if they had higher percentage of protein. Crosses between winter and spring wheats now under way may result in lines that have higher protein content and better gluten characteristics.

In durums, the laboratory screens F₃ and F₄ lines for pigment content and tests advanced lines for macaroni making quality. Testing durum grain for pigment began in 1972 and the results of selection are now showing in advanced lines. The average pigment content of lines has risen from 3.8 ppm to 5.5 ppm and a few lines were found in 1975 that have 10 ppm. In 1975, 5500 durum lines from segregating generations were screened for pigment content, and 900 advanced lines were evaluated for macaroni quality.

In triticale, 350 high yielding lines that have high test weight were evaluated in standard milling and baking tests and for quality of cookies, tortillas, and chapatis made from the lines. Several lines had desirable characteristics and they will be used as parents in future crosses.

COOPERATION WITH NATIONAL PROGRAMS

CIMMYT continued its cooperation with national wheat programs in nearly all developing countries where wheat is an important crop.

In 1975 the wheat staff spent 1104 man days (3 man-years) consulting with governments of wheat-producing countries in Asia,

Africa, and Latin America, or discussing collaborative research at other research institutions. Consultation in developing countries involves observing CIMMYT nursery materials grown by collaborators, visits to farmers' fields to see the condition of the crops, participation in national and regional workshops, and meetings with agricultural officials.

CIMMYT continued to supply experimental seed to 90 countries including virtually every developing country which grows wheat between 30° N and 30° S.

Nine members of CIMMYT wheat staff were posted in five national research and production programs: Algeria, Nepal, Pakistan, Tunisia, and Turkey.

Arrangements for regional wheat programs took concrete form. In 1975 one CIMMYT staff member supervised the early warning system for wheat/barley diseases in the Mediterranean and Mideast, and a second pathologist is being added to that regional activity in 1976. One CIMMYT wheat breeder took up duties in Kenya in 1975, where he is conducting a regional high altitude summer nursery and consulting with governments of East Africa.

One senior wheat breeder will be posted in Ecuador in 1976, serving the wheat-growing countries of the Andes.

Each regional program involves some parallel activities: regional staffing, regional nurseries, regional workshops, assistance to training within national programs, and an annual progress report to help stimulate national program efforts.

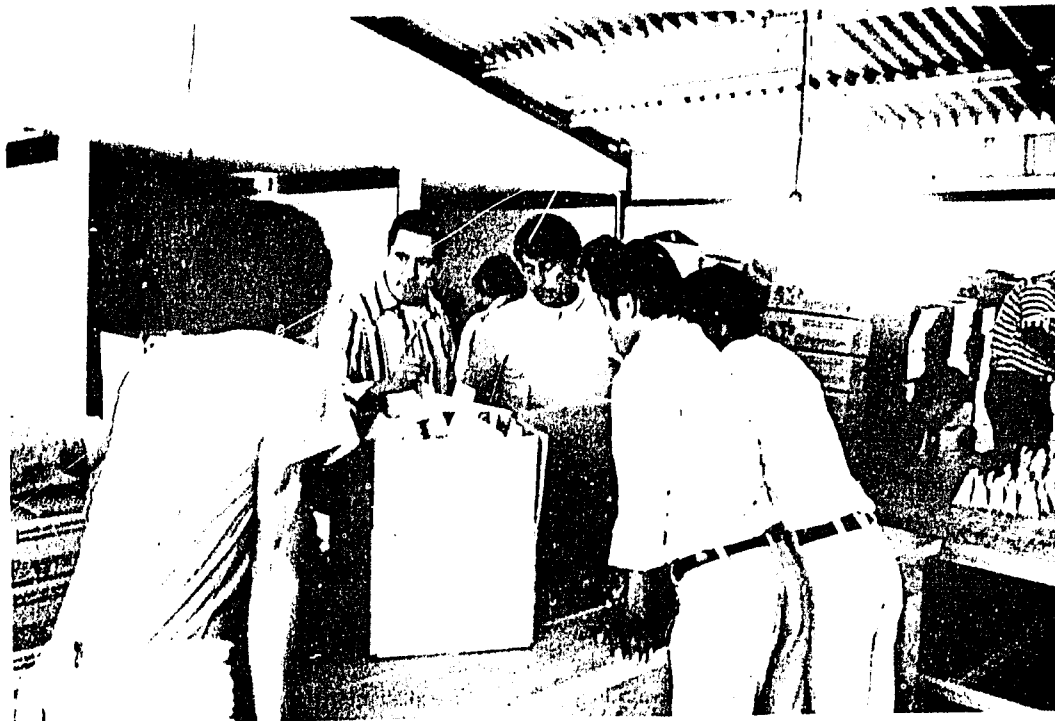
1976-80 FORWARD LOOK FOR WHEAT

At an internal review, late in 1975, the CIMMYT staff discussed the aims and expectations for the wheat program for the period, 1976-80. While predictions are hazardous and necessarily subject to change, the following expectations were endorsed:

Yield stability Significant gains in yield stability are becoming evident for bread wheats, durums, and triticale, and this trend is expected to continue during the last half of the 1970's, and will extend to barleys as well. Wider adaptability leads to greater buffering of climatic differences from year to year at each farming location.

Multilines of wheat are likely to enter widespread commercial use in such countries as India, Pakistan, Egypt, Algeria and Kenya. The multiline principle offers greater stability in disease control.

Slow rusting, another characteristic already introduced to many



Max Alcalá gives instructions for assembling one of the many wheat trials CIMMYT sends out each year.

CIMMYT wheat lines, will continue to spread throughout the parental materials, and thus to new varieties.

Horizontal resistance to major diseases should become more pronounced as world wide selection continues over years.

During 1976 to 1980, a major effort will be made to stabilize resistance to leaf rust, which currently exhibits a great range of virulence.

Bread wheats

CIMMYT scientists anticipate significant additional gains for bread wheats in the last half of the 1970's, each affecting particular "niches" where bread wheat yields are now constrained. These constraints include resistance to septoria (significant around the Mediterranean, in East Africa and South America), tolerance to aluminum toxicity (notable in Brazil), greater drought tolerance (from winter wheat x spring wheat crosses, benefiting dryland wheat areas), and wheat adapted to the cooler winter season in the lowland humid tropics (a product sought by countries in Central America, West Africa, and southeast Asia). Each development would increase the flexibility of wheat in one or more niches, and provide an increment to world wheat production.

Durum wheats	Current research on durum wheats is expected modify new commercial varieties by 1980, including better disease resistance, particularly for septoria, stem rust, and scab; better fertility (fewer empty spikelets); greater cold tolerance; better industrial quality for pasta making; greater drought tolerance; earlier maturity; and increased yield through enhanced head length and grain size.
Triticale	The germ plasma base of triticale was greatly broadened during 1970 to 1975 and should be broadened as much again during the next 5 years. Gains should continue in reducing seed shrinkage, improving disease resistance, and raising yields. The economic advantages of triticale over wheats, notably superior performance on acid soils, should lead to its commercial adoption in India, Ethiopia, Algeria, Kenya, Brazil, and Argentina. Already triticale varieties are available which are suitable for cake flours, animal feeds, animal forage, and for use in the malting and distilling industries. Triticale's high lysine content makes it of interest to protein short countries. Triticale should invade some of the bread wheat areas by the end of the decade, and move outward into areas where its cold tolerance and adaptability to problem soils will expand production on the margins of world agriculture.
Barley	By the end of this decade, the first food barleys derived from CIMMYT materials should be released for use in moisture deficient or short season areas where wheat has been unsuccessful. These newly released varieties will stress short stiff straw, early maturity, genetic resistance to major diseases, improved protein quality, naked kernels, and high yields.
Disease warning systems	By 1980, the disease surveillance system for wheat, barley and triticale in the Eastern Hemisphere is expected to provide a 2 to 3 year warning of the outbreak of new races of rust diseases, before they can reach epidemic proportion in commercial crops. This system is designed to identify, for governments of the region (Morocco to India), commercial varieties which are endangered, and to recommend replacement varieties which should be increased for distribution to avoid epidemics. Partial services will also be operating for East Africa and for South America.
Summer nurseries and other regional services	For some years CIMMYT has helped interested governments to grow two crops of experimental wheat a year, by sending their seed to Mexico for growing in the off season. Now a similar service is provided to the Eastern Hemisphere by the Kenyan government with assistance

of 1 CIMMYT wheat breeder posted there. Off-season activity will be expanded during 1976/80.

CIMMYT expects its regional wheat activities in Western Asia, East Africa, and South America to be fully operational by 1980.

Staff posted in national programs

CIMMYT will continue to post a few wheat scientists to national programs until the end of the decade, but the number is expected to drop. In 1976 CIMMYT staff are posted to Algeria, Tunisia, Turkey, Pakistan, and Nepal.

Local scientists

CIMMYT expects national scientists working in their own national wheat programs will be greatly strengthened during 1976/80. CIMMYT will continue to train about 50 young wheat scientists a year in Mexico (or about 250) over the next 5 years. "Training the trainers" will become a recognized feature of this program, and the trainers will return to their home countries to organize local courses for production agronomists. CIMMYT staff travelling from Mexico will assist these local courses.

Measurement of progress

CIMMYT is prepared to have the progress of its wheat program for the rest of the decade judged by increased stability and disease resistance among bread wheat, durum, barley, and triticale developed in Mexico, by the decisions of national programs to release new varieties they select from materials circulated from Mexico, and by the maintenance and enhancement of yields in farmers' fields.

supporting services



ECONOMIC STUDIES

The economics section supports CIMMYT's efforts to help national programs develop and diffuse new maize and wheat technology. It does this by 1) working with agricultural scientists and policy makers in identifying ways to make new technology and policy more consistent with farmers' circumstances, 2) joining with CIMMYT maize and wheat staff in their training programs, and 3) providing information which the maize and wheat programs can use in setting their own priorities.

Adoption studies

CIMMYT's first major effort in economics was a series of adoption studies conducted from 1972 to '75. These were designed to see how patterns of adoption of new maize and wheat technologies were shaped by the combined influence of such factors as farmers' age, education, and tenure status, the farm's agro-climatic location and distance from markets, and government policy in giving farmers access to inputs and information. Several of the studies have been published by CIMMYT. Work is proceeding on inter-country comparisons between the studies.

To date the analyses support several general statements:

Farmers rapidly take up varieties which suit their environments, with larger farmers usually among the first to adopt but with smaller farmers following quickly.

Three cases distinguish the influence of farm size on adoption of new varieties: 1) Where few larger farmers adopt, few smaller farmers adopt. 2) Where most larger farmers adopt, most smaller farmers adopt. 3) Where an intermediate proportion of larger farmers adopt, fewer smaller farmers adopt. But detailed investigations of one region in which case 3 exists suggest that apparent influence of farm size on adoption is not real. Instead the true explanation lies in agro-climatic heterogeneity within the region.

Fertilizers are adopted less quickly than new varieties and tend to be used at lower rates than are recommended. Farm size generally influences fertilizer use; smaller farmers apply less fertilizer than larger farmers in similar agro-climatic circumstances.

Few of the other variables characterizing the farmer and the farm make any significant contribution to the explanation of the adoption of improved varieties or of fertilizer. One which tended to be significant was degree of specialization in maize or in wheat. This variable was usually positively related to adoption of elements of the new technology and was significant both statistically and operationally. For all other variables —e.g. education, tenure, off-farm work, distance

to markets and various relationships were not consistent, were not statistically significant, and even they tended not to be statistically significant.

Finally, the studies show that government policy facilitates the diffusion of new technology in several ways. One is by providing favorable price ratios. A second is by providing widespread access to inputs as well as to information. But what stands out from the studies is the marked interference of government in the technology adoption process. It is made to appear that government is the only actor responsible to ensure that research results could be used and that the technology truly fit the needs of the farmers for whom government has the strongest concern.

Some additional work on the synthesis of the adoption studies remains to be done. It is planned that this will be completed in 1976.

Developing technology adapted to farmer circumstances

The findings of the adoption studies suggest that there could be large payoffs to more careful evaluation of the agro-climatic and economic circumstances of farmers *at the time new technologies are being developed and tested*, rather than after farmers have either rejected or accepted them. Such research, we believe, would considerably enhance the probability that the technologies developed and recommended will indeed fit farmers' circumstances and, as a result, be more quickly adopted.

To be effective the research would have to combine the skills of economists and biological scientists in a collaborative effort. The economics section therefore began in 1975 to test the value of such work in national crop improvement programs and to evaluate methods which can be used. If preliminary studies verify that this collaborative research is feasible and productive, we expect that the future work of the economics section in this area will be to facilitate and encourage such work by indigenous economists working within the national crop programs which cooperate with CIMMYT.

The economic section has five studies of this type under way: two in Mexico and one each in Zaire, Tunisia, and Pakistan. The Mexico studies are being conducted by Mexico-based economists, in collaboration with the maize training staff for a study in maize in the Poza Rica area, and in collaboration with the wheat training staff for a study of a wheat/barley area near CIMMYT headquarters. The studies in Zaire (maize), Tunisia (wheat), and Pakistan (maize), are being conducted by indigenous agricultural economists in close cooperation with CIMMYT maize and wheat staff members in those countries.

Economics training for agriculturists

Related to the program aimed at adapting technology to farmer circumstances is the economics component of the maize and wheat training programs. The aim is to make trainees more sensitive to the factors which are important to farmers as they evaluate new technologies. Emphasis is also given to providing trainees with procedures which they can use in making recommendations to farmers.

All CIMMYT trainees receive lessons in experiment station management and procedures.



To supplement these efforts and to complement CIMMYT's work with national programs, the economics section is publishing an economics manual for agronomists. The manual highlights the elements that influence the farmers' views of the practices that he follows and provides a simple checklist for accommodating those views in experimentation and in fashioning recommendations.

Crop research priorities

Priorities within CIMMYT are established by the two major programs, maize and wheat, along with the central administration. Economics studies contribute to the deliberations with information and analyses on relevant topics.

With the advent of regional programs in maize and wheat, additional emphasis went to this activity. During 1975 the wheat economy of the Andean Region was examined. In addition, to historical data on wheat production, consumption, and trade, the study reports information on the extent and type of resources committed to wheat research and extension activities. The study also traces changes in government policy on wheat prices, input prices, storage and price support programs, and trade.

The economics section also engages in *ad hoc* studies in support of the maize and wheat programs. One such project related to the nutritive needs of humans and how these needs are being met in selected countries. This involved establishing collaborative relations with nutritionists and with researchers concerned with nutritive deprivation in particular countries. The resulting information is of value in setting breeding priorities within the maize and wheat programs.

LABORATORY SERVICES

The protein laboratory and the plant nutrition and soils laboratory serve both the wheat and the maize programs.

Protein quality laboratory

During 1975, the protein laboratory tested 17,400 maize samples for protein and tryptophan content by colorimetric methods. This is nearly three times the number of samples tested a year earlier. Measuring tryptophan, a limiting amino acid in the endosperm protein gives an indirect indication of the level of lysine, the first limiting amino acid, so the colorimetric method is a rapid way to determine the protein quality of maize. The chemical evaluation is essential for confirming that high-quality protein exists in maizes that have the

opaque-2 gene combined with modifier genes which give normal-appearing kernels.

The laboratory used dye-binding capacity (DBC) procedure to evaluate lysine content in 200 samples of sugary-2 x opaque-2 crosses, in which high content of reducing sugars interferes with the colorimetric method used for tryptophan. Since the kernels of flinty maizes are visually identical to opaque kernels, opaque-2 segregates from opaque-2 x flinty-1 crosses cannot be identified visually. Opaque-2 kernels however have a higher content of free amino acids than normal kernels. The ninhydrin test is used to measure the level of free amino acids. Since this test doesn't destroy the kernels, the kernels identified to be opaque-2 can subsequently be planted. In 1975 the laboratory identified opaque-2 segregates in seeds of 350 families and the selected seeds were later planted in the field.

Analyses for protein content, using the micro-Kjeldahl procedure, and for quality, using DBC, were also made on 5300 barley samples, 3000 triticale samples, 1500 wheat samples, and 283 sorghum samples.

The plant nutrition and soils laboratory does chemical analysis for samples of soil, water, plant tissue, and grain. To assist the physiologists who are increasingly interested in translocation of nutrients from vegetative plant parts to the grain, research was begun on efficient ways to measure sugars in stems and leaves at different stages. During 1975, the laboratory tested 365 samples of soil for pH, organic matter, nitrogen, and assimilable ions (calcium, magnesium, potassium and phosphorus). In addition, 6400 samples of plant tissue primarily were tested for content of nitrogen and total sugars.

Nutrition studies

CIMMYT has no facilities for conducting animal assays to determine the nutritional quality of grain. Instead CIMMYT supplied samples of grain to established nutrition researchers in Guatemala, Mexico, and Denmark for animal assays during 1975.

At the Instituto de Nutricion de Centroamerica y Panama in Guatemala, Dr. R. Bressani and colleagues used rats to evaluate the protein efficiency ratio (PER) of four triticale samples and five maize samples of high-quality in 8 percent protein diets. The PER of the triticales ranged from 1.71 to 2.00 compared with 1.27 for Yecora, the bread wheat check. The quality protein maizes with hard endosperm had about the same PER values (2.14 to 2.41) as the soft endosperm lines. The casein diet had a PER of 2.86.

Sixteen triticale samples were tested as the source of protein in diets of growing rats. These trials were conducted by Dr. A.S. Shimada at the Instituto Nacional de Investigaciones Pecuarias in Mexico. No

significant differences were found between the lines in their effect on the growth rate of rats. Similar trials were conducted with two hard-endosperm, quality-protein maizes; they showed that their nutritional quality was equal.

The laboratory of Dr. B.O. Eggum in Denmark evaluated samples of three triticales and four maizes. Net protein utilization (NPU), which reflects nitrogen retention in the body, was high for triticales (62 to 65) and maize (about 70 for both hard-endosperm and soft-endosperm quality protein maizes). Normal maize had an NPU value of 57.

EXPERIMENT STATION MANAGEMENT

CIMMYT conducts research at eight sites in Mexico. Four are owned by Mexico's National Agricultural Research Institute (INIA) and four are operated by CIMMYT. Some characteristics of these stations:

<i>Station</i>	<i>Elevation</i>	<i>Latitude</i>	<i>Hectares used by CIMMYT</i>
CIANO-INIA	Sea level	27°N	130
Los Mochis-INIA	Sea level	25°N	2
Navojoa-INIA	Sea level	27°N	10
Rio Bravo-INIA	Sea level	26°N	1
Poza Rica-CIMMYT	Sea level	20°N	39 (twice a year)
El Batán-CIMMYT	2240 m	19°N	44
Toluca-CIMMYT	2640 m	19°N	69
Tlaltizapan-CIMMYT	940 m	18°N	31 (twice a year)

The four stations operated by CIMMYT are now fully developed. Land has been fenced, leveled, provided with field roads, and equipped with drainage and irrigation facilities. Crop buildings are complete, but trainee facilities for sleeping and eating have been postponed.

The amount of summer crop land on the high plateau is inadequate to serve the winter crops moving back and forth from the lowland. CIMMYT has therefore rented 12 hectares each summer since 1974.

The Poza Rica station was severely damaged by floods which followed hurricane Fifi in September 1974, removing top soil from the station and leaving deep gullies in the fields. The damage was repaired in 1975.

Scientists from Pennsylvania State University (USA) helped CIMMYT to analyze the soils of El Batán, Tlaltizapan, and Toluca during 1975.

Since 1973, experiment stations managers from national programs have been trained at CIMMYT (Pakistan, Ivory Coast, Egypt, Brazil,

Zaire). Six managers from three countries have been accepted for 1976. The experiment station staff also gives short courses on station management to all 100 maize and wheat trainees a year.

The experiment station head spends several weeks each year as consultant to national programs on station management. So far,

Publications issued in 1975

Title	Language	Pages	Press run
<i>Bulletins and reports</i>			
This is CIMMYT	English	46	2000
	Spanish	48	2800
CIMMYT Review 1975	English	104	4000
	Spanish	112	3500
CIMMYT 1974 Maize Improvement	English	64	2000
The Potential for Increasing Cereal and Livestock Production in Algeria	English	54	500
	French	72	500
India's High Yielding Varieties Programme in Wheat 1966-67 to 1971-72	English	35	1000
The Diffusion of Hybrid Maize in Western Kenya	English	57	1000
Results of the 4th and 5th International Bread Wheat Screening Nursery 1970-72	*	39	1000
Results of the 9th International Spring Wheat Yield Nursery 1972-73	*	136	1200
Results of the 4th International Durum Yield Nursery 1972-73	*	60	1000
Results of the 5th International Durum Yield Nursery 1973-74	*	66	1079
Results of the 4th International Triticale Yield Nursery 1972-73	*	47	1000
Results of the 1st to 5th International Durum Screening Nursery 1969-74	*	70	1074
<i>Reprints</i>			
Some ways International Research Programs can Assist Advanced Nations	English	8	500
National Production Programs for Introducing High-quality Protein Maize in Developing Countries	English	9	500
	Spanish	8	500
A Comparison of Maize Diseases in Temperate and Tropical Environments	English	10	500
	Spanish	11	500
The Field Support Functions of the Agricultural Experiment Stations in the Developing Countries	English	16	500
	Spanish	16	500
Potential for Improving Production Efficiency of Cereals	English	9	500
	Spanish	10	500
Developing Agricultural Research Personnel	English	9	500
	Spanish	9	500
The Uneven Prospects for gains from agricultural Research Related to Economic Policy	English	8	500
	Spanish	8	500
<i>CIMMYT Today</i>			
Quality Protein Maize	English	16	5500
	Spanish	16	5600
Durum Wheat: New age for an old crop	English	16	3800
	Spanish	16	5200
The return of medic	English	16	4600

*Text in English, Spanish, and French.

this work has involved Pakistan, Nepal, Philippines, Tanzania, Nigeria, Ivory Coast, Algeria, and Turkey. In 1975 he helped the International Rice Research Institute in the Philippines plan the development of its new land. Three Asian countries have asked help in 1976, and others are on a waiting list for subsequent years.

INFORMATION SERVICES

Eighteen new titles were published during 1975. In addition the general information booklet *This is CIMMYT* was revised and reissued. Most bulletins, reports, and reprints were published in two languages (English and Spanish) or in three languages (English, Spanish and French).

A new serial, *CIMMYT Today*, was begun and three issues were published during the year. Articles in *CIMMYT Today* treat broad aspects of CIMMYT's activities for the informed layman.

The Proceedings of the CIMMYT-Purdue International Symposium on Protein Quality in Maize, 1972, were published as a 500-page, hardcover book for CIMMYT by Dowden, Hutchinson, and Ross (USA) under the title *High-Quality Protein Maize*.

CIMMYT started a new journal of abstracts called *Maize quality protein abstracts*. This journal is published for CIMMYT by the Commonwealth Agricultural Bureau (U.K.) with funds from the United Nations Development Program. Volume 1 (1975) consists of four issues containing 145 abstracts. In addition, a retrospective volume covering world literature published between 1960 and 1974 relating to the protein quality of maize was issued. This volume contains 337 abstracts. About 600 maize scientists receive MQPA.

Mailing list About 800 individuals and institutions asked to be included in the CIMMYT mailing list during 1975, increasing the total mailing list to 4900 individuals and 500 libraries. Half the addresses on the list are in Spanish-speaking countries.

The mailing list was coded to allow more selective distribution of publications.

Audiovisuals The permanent exhibit in the administration building was completely reorganized and many new displays were added. The exhibit depicts CIMMYT's activities in increasing world food supplies. The audiovisual section continued its support of the crop programs with artwork and photography.

- Visitor services** In 1975 over 5000 visitors from 55 countries were registered at CIMMYT headquarters, both individually and in groups. Many others visited other CIMMYT research stations, where no records are kept.
- Library services** CIMMYT's small working library (2500 volumes, 1200 serials) continued to offer services to the headquarters staff, postdoctoral fellows, and 100 training fellows. The CIMMYT library also serves as liaison with Mexico's National Agricultural Library (50,000 volumes, 3000 serials) which is located 10 km from CIMMYT.

STATISTICAL SERVICES

A biometrician loaned by the U.K. Ministry of Overseas Development arrived at CIMMYT during 1975. Pending the arrival of the unit's own computer (Data General Nova 3 64K with two discs and various other peripherals), CIMMYT has used a Nova 2 loaned for demonstration purposes by the suppliers.

With programs adapted by the University of Colorado (USA), the borrowed machine has had no problem in analyzing the international maize trials quickly. This computer was also used to demonstrate the application of the EXIR system for processing information from CIMMYT's maize germ plasm bank.

At present the taximetries laboratory of the University of Colorado is working on a program for the wheat trials. When the new computer arrives and a programmer is hired, it should be possible to handle all CIMMYT's computational requirements.

Temporarily, CIMMYT's economics program is still using outside contract services for part of its statistical work.

CIMMYT's payroll and accounting services are now handled by in-house equipment.

special reports



SPECIAL REPORT
IMPACT OF THE HIGH YIELDING WHEATS: \$2,000,000,000
A YEAR

Independent economists are now arriving at answers to the question: What is the impact of the high yielding wheats? Economists are measuring the area of planting, the rising production, the average yields compared with traditional varieties, and the gross value of increased food. No one has yet produced an orderly sequence of data on all these questions but the general magnitude of the answers is well established.

Two leading chroniclers of the high yielding varieties are Dana G. Dalrymple and Robert Evenson. Dalrymple is an analyst for the Economic Research Service, U.S. Department of Agriculture. Evenson is an economist with the Agricultural Development Council and is presently a visiting scholar at the College of Agriculture, University of the Philippines, Los Baños. Both have published a number of studies on the high yielding varieties in the 1970's.

Some of their calculations are excerpted below, but CIMMYT alone takes responsibility for the arbitrary selection of data and the projections across the developing world.

How widely are the new wheats grown?

Dalrymple has assembled data on the planting of high yielding wheat in 15 countries of South Asia and North Africa. He concludes that at least 19.3 million hectares of the new wheats were planted in those 15 countries in the crop year 1974/75.

Five developing countries which planted the largest areas contributed over 80 percent of the new wheats:

India	11,800,000 ha.
Pakistan	3,700,000

Iraq	800,000
Turkey	700,000
Afghanistan	500,000

Comparable data has not yet been published on the planting of the new wheats in eastern and southern Africa or Latin America. When that data is added, the new wheats will undoubtedly be found to cover more than 25 million hectares in developing countries in 1975, or 40 percent of the total wheat area in the developing world.

Increased yields? The best data on yields of the short wheats have come from India and Pakistan.

In India the high yielding wheats out-produced the traditional varieties by 200 percent during 1965-70 (roughly 2400 kg/ha compared with 800 kg/ha). But as the proportion of total wheat land planted to the new varieties increased, the superiority in yields declined, until at the end of 8 years, the superiority in yields of the new varieties over the old was approximately 125 percent (roughly 1600 kg/ha compared with 700 kg/ha).

Another study of both India and Pakistan shows that national average yields of wheat rose 50 percent in these two countries between 1966 and 1973. This study encompasses both the new varieties and the traditional.

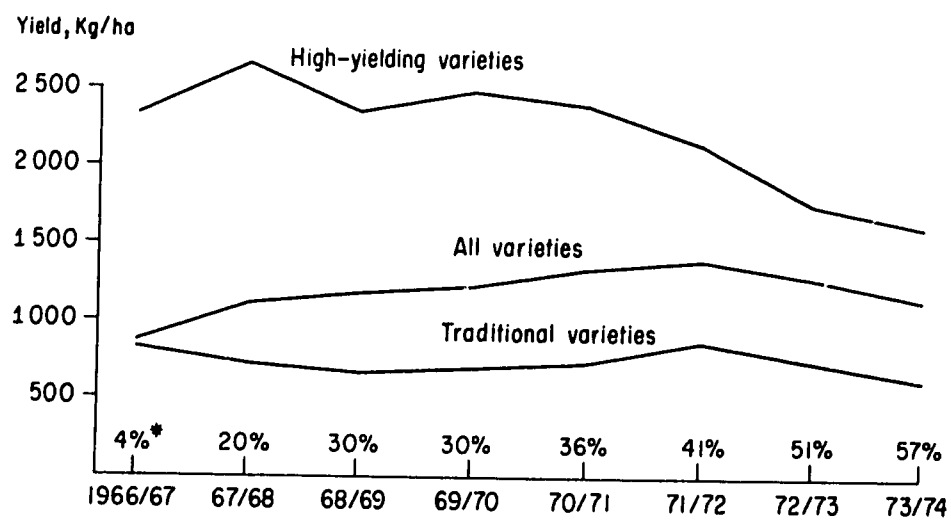
Since India and Pakistan contain a large share of the land planted to the new wheats, the following generalization can be made: when high yielding wheats are introduced to an ecological zone where they are adapted (such as the Punjab of India and Pakistan), and they spread to cover half the national wheat area, they will outyield the old tall

High yielding wheats in South Asia and the Mideast, 1965-1975. Area planted and percentage of total wheat area planted to high-yielding varieties based on estimates of the U.S. Department of Agriculture.

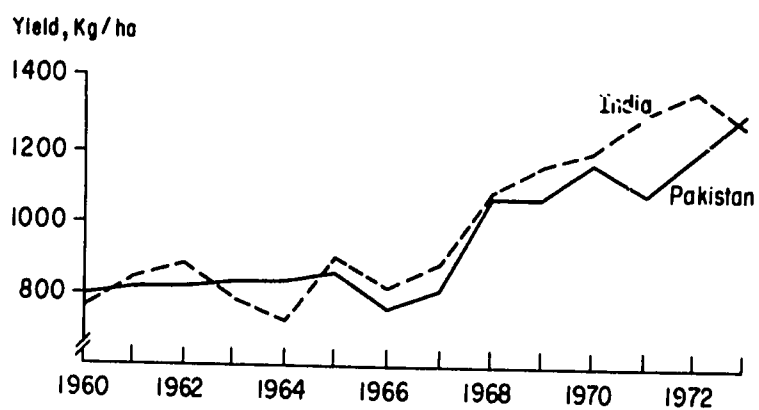
Year	Bangladesh		India		Nepal		Pakistan		Total South Asia	Afghanistan		Algeria		Egypt		Iran	
	000 ha.	%	000 ha.	%	000 ha.	%	000 ha.	%	000 ha.	000 ha.	%	000 ha.	%	000 ha.	%	000 ha.	%
65/66	—	—	3	*	1	1	5	*	9	—	—	—	—	—	—	—	—
66/67	—	—	540	4	6	5	101	2	648	1	*	—	—	—	—	—	—
67/68	—	—	2942	20	24	13	957	16	3923	22	1	—	—	—	—	—	—
68/69	8	7	4792	30	53	26	2387	38	7242	122	4	—	—	—	—	10	*
69/70	9	7	5004	30	75	34	2681	43	7771	146	5	5	2	—	—	37	1
70/71	13	12	6542	36	98	43	3128	52	9782	232	9	140	7	—	—	63	2
71/72	15	12	7858	41	115	52	3286	57	11275	255	10	320	14	1	*	125	3
72/73	21	18	10007	51	170	66	3375	56	13576	450	15	600	28	20	4	138	3
73/74	29	23	10911	57	206	76	3472	59	14619	475	16	na	na	212	40	261	6
74/75	33	23	11778	62	246	85	3682	62	15741	522	17	na	na	78	14	292	7

	Iraq		Lebanon		Morocco		Saudi Arabia		Syria	Tunisia		Turkey		Total Mideast	Total
	000 ha.	%	000 ha.	%	000 ha.	%	000 ha.	%	000 ha.	000 ha.	%	000 ha.	%	000 ha.	000 ha.
65/66	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9
66/67	—	—	—	—	—	—	—	—	—	—	—	1	*	2	651
67/68	6	*	—	—	—	—	—	—	—	1	*	170	2	199	4123
68/69	41	2	—	—	5	*	—	—	—	12	2	579	7	770	8012
69/70	195	10	2	4	46	2	—	—	—	53	7	623	8	1108	8879
70/71	125	9	7	12	90	5	—	38	4	102	11	640	8	1437	11219
71/72	950	45	12	19	206	10	—	75	7	60	6	650	8	2654	13930
72/73	595	50	20	31	294	14	—	180	15	99	9	na	na	3046 ^a	16623
73/74	700	43	na	na	375	20	2	225	15	55	6	na	na	3575 ^b	18195
74/75	750	50	na	na	300	17	10	252	16	54	6	na	na	3528 ^b	19269

* Negligible. ^a/ Including Turkey at 1971/72. ^b/ Including Algeria and Lebanon at 1972/73 level and Turkey at 1971/72 level.



India: Trends in yields for traditional and high-yielding wheat varieties.
 *Proportion of total wheat area planted to high-yielding varieties.



Trends in wheat yields in India and Pakistan. Source: USDA.

wheats by 100 percent and raise the national average yield of wheat by 50 percent.

Increased production and value. Evenson has published several studies on increased wheat production which is "associated" with the new varieties and the related package of practices.

Focussing on 10 countries of Asia and the Mideast, he calculated the share of increased wheat produced in those countries in 1972/73 which was "associated" with the new wheats. Then he extrapolated the share of wheat production in all developing countries which was "associated" with high yielding varieties in 1972/73. Next, the value of increased wheat production was arbitrarily priced at US\$75 a ton (an

approximation of the price of wheat moving in international trade in 1972.) From these three steps Dr. Evenson concluded that the wheat revolution had added \$906 million to the income stream of developing countries in 1972/73.

In 1975 the price of wheat moving in international trade had risen to approximately \$150 a ton or double the unit price used by Evenson. Therefore the impact of the wheat revolution in 1974/75 can be placed at \$1800 million.

Even this figure is complete. Planting semi-dwarf wheats in countries of Asia and the Mideast rose 15 percent after Evenson made his calculations. Therefore a rounded value of \$2000 million for the new wheats in 1975 in developing countries would be conservative.

SPECIAL REPORT

COOPERATIVE PROGRAMS WITH OTHER INTERNATIONAL AGRICULTURAL INSTITUTES

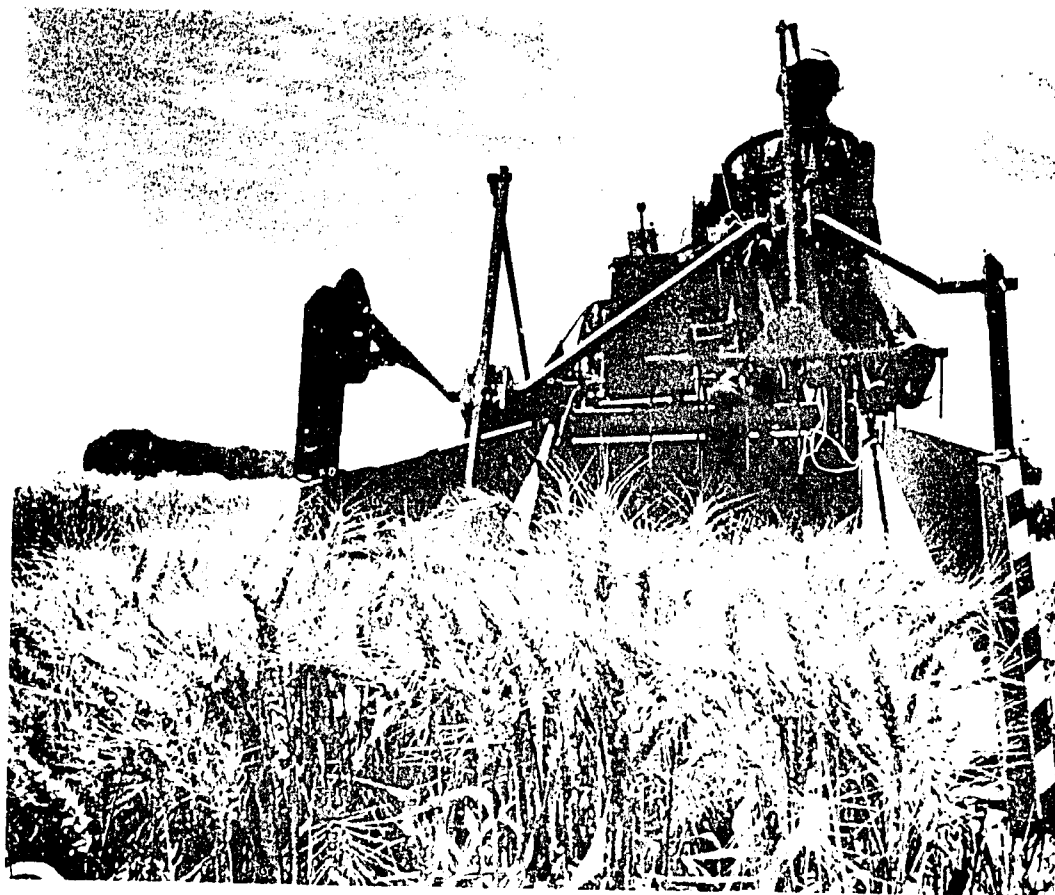
CIMMYT is engaged a number of joint programs with other international agricultural institutes. Some examples:

Potato research. Since 1972 the International Potato Center (CIP) has used land, labor, and machinery on CIMMYT's Atizapan station in Mexico, under a service agreement which enables CIP to expose potato germ plasm to the world's most severe attacks of late blight, a potato disease, and to select for resistance. CIP directs the Mexico research from its headquarters in Peru, and reimburses CIMMYT for the service costs.

Maize improvement in the Andean region. Beginning in 1976, CIMMYT is posting three maize staff members to the Andean

Region, under a joint program with the International Center of Tropical Agriculture (CIAT). Two of the CIMMYT-CIAT scientists will reside at CIAT headquarters in Colombia, where they will give leadership to cooperative maize activities among five Andean governments. One scientist will be posted to Quito, Ecuador, to assist research on soft maize which is a major crop in the Andes. This regional program will be jointly planned between CIMMYT-CIAT; and costs will be financed by CIMMYT through special grants. Both centers will share in training.

Maize improvement for Asia. Beginning in 1976 two CIMMYT maize staff will be posted to the International Crops Research Institute for the Semi Arid Tropics



A trainee learns to operate a plot harvester.

(ICRISAT) in India, to provide leadership for maize improvement among about 15 Asian countries from Afghanistan to Indonesia. CIMMYT pays all costs of services at ICRISAT. CIMMYT will draw upon ICRISAT administrative support, and ask some agricultural services for seed increase, on a reimbursable basis. The posted CIMMYT staff will spend much time consulting with governments in the region. The ICRISAT service agreement is somewhat different from the CIMMYT CIAT effort described above.

Cold-tolerant sorghum at CIMMYT headquarters. Since the 1950's CIMMYT maize breeders have devoted marginal

resources to a breeding program for cold-tolerant sorghum adapted to tropical elevations above 2000 meters, believing that sorghum should perform better than maize in this climatic zone. Beginning in 1977, ICRISAT is expected to finance and staff this program at CIMMYT headquarters, on a cooperative basis similar to the potato project above.

Maize improvement in tropical Africa. Beginning in 1976 the International Institute of Tropical Agriculture (IITA) and CIMMYT have agreed to make joint plans for their respective activities in maize improvement for tropical Africa. This includes breeding at CIMMYT for resistance to streak virus

disease, and the testing for streak resistance at IITA and elsewhere in Africa, to overcome one of the most severe constraints to maize production in Africa. No transfer of personnel or funds is proposed between IITA and CIMMYT.

Cooperation in Kenya. CIMMYT has posted to Kenya one regional wheat scientist and one regional economist. By agreement with the International Laboratory for Research on Animal Diseases (ILRAD), these CIMMYT staff members will draw upon administrative services of ILRAD, on a reimbursable basis, as the new livestock disease laboratory develops its own facilities and staff, and finds it possible to share its services.

Joint administrative arrangements in national programs. Recent outreach discussions in Pakistan, Nepal, and elsewhere have developed the need for common administrative services, available

to all international centers operating in the same country. In Pakistan these common facilities are taking shape under sponsorship of the Agricultural Research Council, which is entering into separate usage agreement with CIMMYT, IRRI, CIP, and possibly other centers. Likewise, in Nepal common services are evolving under sponsorship of the Ministry of Agriculture with help from the International Agricultural Development Service. These services will be available initially to CIMMYT, IRRI, and CIP. This is a flexible pattern, likely to be adopted or adapted by other national programs.

Proposed program on wheat and barley improvement. CIMMYT trustees have recommended to the trustees of the International Center for Agricultural Research in Dry Areas (ICARDA) that a joint ICARDA-CIMMYT program should be devised for wheat-barley improvement in the Mediterranean and Mideast region.

SPECIAL REPORT

CIMMYT'S EXPERIENCE WITH DOCTORAL FELLOWS, 1966-1976.

CIMMYT has supervised 88 fellowships for postdoctoral and predoctoral fellows during the decade ending 1976. These fellows are listed below. When the staff recently reviewed this CIMMYT training experience, they found some interesting facts which will help to shape future awards.

Postdoctoral fellowships. The postdoctoral fellow at CIMMYT generally

holds a 2-year appointment to serve as a research associate, engaged in professional investigation alongside the international staff. CIMMYT accepts fellows only if the work they can perform will contribute directly to CIMMYT's core program.

In the 10 years ending 1976, 43 postdoctoral fellows from 19 countries received experience at CIMMYT. Twenty-

Postdoctoral fellows at CIMMYT, 1966-76.

Name and discipline	Origin	Period	Funding source *	Subsequent employment
C. De León Maize pathology	México	1967-69	CIMMYT	CIMMYT
G. Díaz C. Maize entomology	México	1967-69	CIMMYT	Mexican Government
G. Kingma Maize breeding	Netherlands	1967-69	CIMMYT	CIMMYT
E. Rodríguez Wheat pathology	México	1968-70	CIMMYT	CIMMYT
A.F.E. Palmer Maize physiology	UK	1968-70	CIMMYT	CIMMYT
S. Jinahyon Maize breeding	Thailand	1968-70	CIMMYT	Government of Thailand
S. Rajaram Wheat pathology	India	1969-71	CIMMYT	CIMMYT
G. Granados R. Maize entomology	México	1969-71	RF	CIMMYT
B. Devecioglu Wheat breeding	Turkey	1969-70	RF-CIMMYT	Government of Turkey
S.K. Vasal Maize breeding	India	1970-71	CIMMYT	CIMMYT
D. MacKenzie Wheat pathologist	USA	1970-72	RF	Asian Vegetable Research & Development Center
V.L. Asnani Maize breeding	India	1970-71	RF	IITA
M.M. Kohli Wheat breeding	India	1971-72	CIMMYT	CIMMYT
K. D. Sayre Potato Breeding	USA	1971-73	RF	CIP
S. Sriwatanapongse Maize breeding	Thailand	1971-73	CIMMYT	Government of Thailand
R. J. Redden Wheat breeding	Australia	1972-74	CIMMYT	IITA
W. L. Haag Maize agronomy	USA	1973-74	RF	CIMMYT
D. H. Ris Lambers Wheat physiology	Netherlands	1973-75	CIMMYT	IRRI
R.N. Wedderburn Maize plant protection	Barbados	1973-75	CIMMYT	CIMMYT
M. A. McMahon Triticale agronomy	Ireland	1973-75	IDRC	CIMMYT

continued

Postdoctoral fellows, continued

Name and discipline	Origin	Period	Funding source *	Subsequent employment
R. McK Bird Germplasm bank	USA	1973-75	RF	University of Colorado (USA)
R. Soza Maize agronomy	Chile	1973-74	CIMMYT	CIMMYT
K. S. Fischer Maize agronomy	Australia	1973-75	CIMMYT	CIMMYT
A. Merker Triticale cytology	Sweden	1973-74	IDRC	Swedish Seed Association
S. P. Singh Sorghum breeding	India	1973-75	IDRC	CIMMYT
E. Moscardi Economics	Argentina	1975-76	CIMMYT	CIMMYT
S. Pandey Maize breeding	India	1974-	UNDP	**
R. A. Kirkby Maize plant protection	UK	1974-	CIMMYT	**
W. A. Stoop Maize agronomy/physiology	Netherlands	1974-	CIMMYT	CIMMYT
J. James Maize wide crosses	UK	1974-	ODM/ CIMMYT	**
H. S. Córdova Maize breeding	El Salvador	1975-	CIMMYT	CIMMYT
H. E. Vilar Wheat breeding	Ecuador	1975-	CIMMYT	**
P. C. Wall Wheat physiology	Ireland	1975-	CIMMYT	**
D. Leihner Wheat agronomy	Germany	1975-	Government of Germany	**
J. B. Thomas Wheat wide crosses	Canada	1975-	CIMMYT	**
T. C. Stilwell Maize agronomy/physiology	USA	1975-	CIMMYT	**
J. A. Mihm Maize plant protection	USA	1975-	CIMMYT	**
P. G. Goertz Maize breeding	Germany	1975-	Government of Germany	**
S. Taba Maize breeding	Japan	1975-	UNDP	**
G. Ortiz Wheat breeding	Mexico	1976-	CIMMYT	**

continued

Postdoctoral fellows, *continued*

Name and discipline	Origin	Period	Funding source *	Subsequent employment
J. Hanson Maize breeding	UK	1976-	CIMMYT	**
V. Rodríguez M. Maize breeding	El Salvador	1976-	CIMMYT	**
B. Skovmand Wheat breeding	Denmark	1976-	CIMMYT	**

* RF = Rockefeller Foundation, IDRC = International Development Research Centre (Canada), UNDP = United Nations Development Programme, ODM = Overseas Development Ministry (UK). *Continuing fellowship.

three of them came from developing countries and the rest from industrialized countries:

Latin America	Europe
Argentina	Denmark
Barbados	Germany
Chile	Ireland
Ecuador	Netherlands
El Salvador	Sweden
Mexico	United Kingdom
Asia	Other
India	Australia
Japan	Canada
Thailand	USA
Turkey	

Twenty-eight of these fellows completed their fellowships by early 1976 and took up employment. CIMMYT believes the choice of employment reveals something about the value of experience they received. Their choice of work included:

Joined CIMMYT staff	17
Joined staff of another international agricultural center	5
Joined research organization in their home government (developing country)	4
Joined a university faculty or a private seed company	2

All these former fellows are employed in the professional field for which they were trained.

Predoctoral fellows. The predoctoral fellow most often spends 12 to 18 months at CIMMYT doing thesis research under CIMMYT supervision to qualify for a doctorate or master's degree. Arrangements are mutually acceptable to the university which will award the degree.

Forty-five predoctoral fellows were received by CIMMYT during the 10 years ending 1976. They came from 18 countries:

Asia	Latin America
Japan	Argentina
Malaysia	Colombia
Pakistan	El Salvador
	Honduras
Africa	Mexico
Algeria	
Cameroon	Other
Egypt	United Kingdom
Ivory Coast	USA
Kenya	
Tunisia	
Uganda	
Zaire	

Predoctoral training fits the needs of most candidates from developing countries, and also the needs of their governments. Hence more than two thirds of the predoctoral fellows at CIMMYT have been from developing countries and most fellows planned to

Predoctoral and M.Sc. Candidates who did thesis research at CIMMYT or under CIMMYT supervision, 1966-76.

Candidate & Institution	Origin	Period	Sponsor *	Subsequent employment *
G. Martínez V. Communications U. Wisconsin	México	1966-67	RF/CIMMYT	CIMMYT
A. Fuente B. Soils Iowa State U.	México	1968-69	RF (Plan Puebla)	Private credit bank
G. Granados Maize entomology Kansas State U.	México	1968-69	RF/CIMMYT	CIMMYT
L. A. Elías B. Maize entomology Kansas State U.	México	1968-69	RF/CIMMYT	Private agrobusiness
R. Coffman Wheat breeding Cornell U.	USA	1970-71	RF/Cornell	IRRI
J. Yamaguchi Maize physiology Hokkaido U.	Japan	1970-72	CIMMYT	Hokkaido University (Japan)
M. Splitter Maize breeding Cornell U.	USA	1970-72	RF/Cornell	CIMMYT
M. Alcalá Agronomy Oregon State U.	México	1970-73	RF	CIMMYT
D. Sperling Maize breeding Cornell U.	USA	1971-72	RF/Cornell	CIMMYT
H. Diaz Agric. Development U. Wisconsin	México	1970-74	RF/CIMMYT	Mexican government
N'G. Bosso Maize breeding Cornell U.	Ivory Coast	1971-75	FF/CIMMYT	Government of Ivory Coast
A.A. Ismail Maize breeding Cornell U.	Egypt	1971-74	FF/CIMMYT	Egyptian Government
D. Midmore Wheat breeding Reading U.	UK	1973-75	ODM	UK Government
I. Timti Maize pathology Kansas State U.	Cameroon	1973-76	FF	Cameroon Government

continued

Predoctoral & M.Sc. Candidates, *continued*

Candidate & Institution	Origin	Period	Sponsor *	Subsequent employment*
F. Bidinger Wheat agronomy Cornell U.	USA	1972-76	RF	ICRISAT
P. Marko Agric. Extension Reading U.	USA	1972-74	CIMMYT	CIMMYT
J. L. Maya L. Wheat breeding Oregon State U.	México	1972-75	RF	Mexican Government
E. Moscardi Agric. Economics U. California	Argentina	1972-75	U. California/ CIMMYT	CIMMYT
J. Cutié Agricultural Economics U. Wisconsin	El Salvador	1972-74	FF/U. Wisconsin/ CIMMYT	University
H. Colmenares Agricultural Economics U. Wisconsin	Colombia	1972-74	FF/CIMMYT	Government of Colombia
J. Gerhart Public administration Princeton U.	USA	1973-75	FF/CIMMYT	FF
S. Gafsi Agric. Economics U. Minnesota	Tunisia	1973-75	FF/Minnesota/ CIMMYT	World Bank
M. Mwamufya Agricultural Economics Oregon State U.	Zaire	1974-	USAID/CIMMYT	**
E. Ortega Biochemistry Kansas State U.	México	1973-75	RF	CIMMYT
B. R. Khan Agronomy Kansas State U.	Pakistan	1973-76	FF	Pakistan Government
M. S. Khan Agronomy Kansas State U.	Pakistan	1973-76	FF	Pakistan Government
A. López B. Pathology Oregon State U.	México	1973-	RF/CIMMYT	**
L. Adem Wheat/Medicago system Waite Agric. Institute	Algeria	1974-	FF/CIMMYT	**

continued

Predoctoral & M.Sc. Candidates, *continued*

Candidate & Institution	Origin	Period	Sponsor *	Subsequent employment *
A. Dahmane Wheat/Medicago system Waite Agric. Institute	Tunisia	1974-	FF/CIMMYT	**
M. Nyanguila Agronomy Kansas State U.	Zaire	1973-76	Zaire Government	Zaire Government
M. Makambo Agronomy Kansas State U.	Zaire	1974-	Zaire Government	**
B. Bimayala Agronomy Iowa State U.	Zaire	1974-	Zaire	**
M. Ngandu Maize agronomy Iowa State U.	Zaire	1974-	Zaire	**
M. Athar Maize breeding Kansas State U.	Pakistan	1975-	USAID/ Pakistan Government	**
R. Maurer Agronomy U. Nebraska	México	1975-	RF	**
P. Brajcich Plant breeding Oregon State U.	México	1975-	RF/CIMMYT	**
B. Muruli Plant Sciences Kansas State U.	Kenya	1975-	FF	**
M. Contreras Maize pathology Cornell U.	Honduras	1975-	RF/CIMMYT	**
D. Galt Agric. Economics Cornell U.	USA	1975-	RF/CIMMYT	**
F. Peairs Maize Entomology Cornell U.	USA	1975-	RF/CIMMYT	**
M. Rodríguez Soils Cornell U.	Colombia	1975-	RF/CIMMYT	**
S. Muchena Maize breeding Cornell U.	Uganda	1975-	RF/CIMMYT	**

continued

Predoctoral & M.Sc. Candidates, *continued*

Candidate & Institution	Origin	Period	Sponsor *	Subsequent employment *
K. Nor Agronomy Cornell U.	Malaysia	1976-	RF/CIMMYT	**
P. Garcia Agric. Economics Cornell U.	USA	1976-	FF/CIMMYT	**
S. S. Shaban Maize pathology Texas A & M U.	Zaire	1976-	Zaire	**

* IRRI = Int. Rice Research Inst. ICRISAT @ Inst. Crops Research Inst. for the Semiarid Tropics, FF = Ford Foundation, RF = Rockefeller Foundation, ODM = Overseas Development Ministry (UK), USAID = U.S. Agency for International Development.

serve their home governments after completing their degrees.

Team research. Six predoctoral fellows from Cornell University (USA) are currently engaged in "team research." That is, they are doing their dissertation research at CIMMYT on related subjects, but for different departments of the university. This group consists of a maize breeder, a maize entomologist, a maize pathologist, a maize agronomist, a soils scientist, and an agricultural economist. In addition to acquiring a basic discipline, each participant receives experience as part of an inter-disciplinary team.

In 1975, five master's degree candidates from Kansas State University (USA) engaged in similar team research at CIMMYT, producing theses on closely related topics, but earning their degrees from different academic departments.

Benefits. CIMMYT's 10-year experience

with postdoctoral fellows suggests that CIMMYT can manage up to 20 fellows in residence in Mexico simultaneously, and the experience received by the fellows can prepare a young scientist from a developing country for serving his own government, or for joining the staff of an international center.

During the past decade CIMMYT recruited 22 new staff members from its postdoctoral and predoctoral fellows.

During the same decade, CIMMYT's international staff positions expanded from 8 to almost 80 (combining headquarters and outreach staff). The doctoral fellows were thus passing through a screening process, as well as a training process.

During the last half of the 1970's, even greater emphasis will be placed on preparing young scientists to serve their home governments in developing countries. This will influence the choice of candidates.

**SPECIAL REPORT
CIMMYT PUBLICATIONS 1965-1975**

Below is a list of bulletins, pamphlets, and proceedings published by CIMMYT during the past decade.

1965

Chromosome morphology of certain races of maize in Latin America. Albert E. Longley and Takeo A. Kato Y. 112 p.

1966

Statistical genetic theory and procedures useful in studying varieties and intervarietal crosses in maize. C.D. Gardner and J.H. Lounquist. 34 p.
Preliminary reports of the first three Inter-American and the first two Near East-American spring wheat yield nurseries. 130 p.
Third Near East-American spring wheat yield nursery, 1963-1965. Charles F. Krull, et al. 66 p.

Teoría genético-estadística y procedimientos útiles para el estudio de las variedades y cruzamientos inter-varietales de maíz. C.D. Gardner y J.H. Lounquist. 34 p.

Trigo híbrido: su potencial para alimentar una creciente población mundial. Ricardo Rodríguez, et al. 48 p.

Germoplasma exótico para el mejoramiento del maíz en los Estados Unidos. E.J. Wellhausen. 23 p.

1967

Fourth Inter-American spring wheat yield nursery, 1963-1964. Charles F. Krull, et al. 56 p.
Hybrid wheats: their development and food potential. Ricardo Rodríguez, et al. 37 p.
CIMMYT annual report 1966-67. 103 p.

Mejoramiento genético del antiploide triticales. Marco Antonio Quiñones Leyva. 98 p.
Informe anual CIMMYT 1966-67. 103 p.

1968

CIMMYT annual report 1967-68. 99 p.
Field technique for fertilizer experiments. Reggie J. Laird. 48 p.
First international spring wheat yield nursery, 1964-65. Charles F. Krull, et al. 98 p.
Second international spring wheat yield nursery. Charles F. Krull, et al. 98 p.
Variability in the lysine content of wheat, rye, and triticales proteins. Evangelina Villegas, et al. 32 p.

Informe anual CIMMYT 1967-68. 99 p.
Técnicas de campo para experimentos con fertilizantes. Reggie J. Laird. 48 p.
Producción de maíz en Centroamérica. Reconocimiento de experiencias en programas de fomento. D.T. Myren and S.G. Manger. 16 p. (reprint).

1969

A modified method for rapid tripotphan analysis of maize. Horacio Hernandez H. y Lynn S. Bates. 7 p.
Combining data from fertilizer experiments into a function useful for estimating specific fertilizer recommendations. R.J. Laird, et al. 30 p.
A green revolution yields a golden harvest. Norman E. Borlaug, et al. 11 p. (reprint).
CIMMYT report 1968-69. 122 p.

Informe anual CIMMYT 1968-69. 122 p.

1970

A survey on stem rust resistance in the USDA world durum collection and in CIMMYT durum breeding lines. S. Rajaram, et al. 25 p.
Third international spring wheat yield nursery, 1966-67. Keith W. Finlay et al. 74 p.
First and second international screening nurseries (1967-1969). David McKenzie, et al. 28 p.
The Puebla Project. 1967-69. 120 p.
Strategies for increasing agricultural production on small holdings. 86 p.
CIMMYT annual report 1969-70. 138 p.
El Proyecto Puebla 1967-69. 120 p.
Estrategias para aumentar la productividad agrícola en zonas de minifundio. 86 p.
Informe anual CIMMYT 1969-70. 138 p.

1971

Bibliography of corn, Vol. I, II, III. 1887 p.
Bibliography of wheat, Vol. I, II, III. 2239 p.
Chemical screening methods for maize protein quality at CIMMYT. Evangelina Villegas and Edwin T. Mertz. 14 p.
Fourth international spring wheat yield nursery, 1967-1968. 77 p.
Fifth international spring wheat yield nursery, 1968-1969. 78 p.
A survey on leaf rust resistance on the USDA world durum collection. S. Rajaram, and J.F. Sartor. 32 p.
Third international bread wheat screening nurseries.

- (series A and B) 1969-1970. David R. McKenzie. 23 p.
- Progress in developing triticale as an economic crop. F.J. Zillinsky and N.E. Borlaug. 27 p.
- Proceedings of the first maize workshop. 107 p.
- CIMMYT annual report 1970-71. 114 p.
- Metodos quimicos usados en el CIMMYT para determinar la calidad de la proteina del maiz. Evangelina Villegas y Edwin T. Mertz. 14 p.
- Informe anual CIMMYT 1970-71. 114 p.
- Methodes chimiques employees par CIMMYT dans la determination et l'evaluation de la qualite de la proteine du maïs. Evangelina Villegas, Edwin T. Mertz. 15 p.
- 1972**
- Sixth international spring wheat yield nursery 1969-1970. 80 p.
- The international wheat and maize nurseries. Handbook for fertilizer conversions to basic units. Dr. R. McKenzie and John Cadavid. 7 p.
- Preliminary summary of the first international elite selection yield trials (1 and 2). A spring wheat yield nurseries, 1969-1970. 11 p.
- First elite selection yield trial 1 and elite selection yield trial 2 1969-1970. 41 p.
- Preliminary summary of the second international elite selection yield trials (1 and 2). A spring wheat yield nursery, 1970-1971. 36 p.
- First international maize adaptation nursery (IMAN) 1970-1971. 55 p.
- First international durum yield nursery 1969-1970. 48 p.
- First international triticale yield nursery, 1969-1970. 53 p.
- Report on the grain quality of the entries in "the seventh international spring wheat yield nursery" 1970-1971. 12 p.
- The green revolution, peace and humanity. Norman E. Borlaug. 38 p. (reprint).
- La revolucion verde, paz y humanidad. Norman E. Borlaug. 38 p. (translation).
- 1973**
- Proceedings wheat, triticale and barley seminar. 378 p.
- Second and third international triticale yield nurseries 1970-71, 1971-72. 103 p.
- Triticale breeding and research at CIMMYT. A progress report. F.J. Zillinsky. 84 p.
- Treatment design for fertilizer use experimentation. Foster B. Cady and Reggie J. Laird. 30 p.
- Seventh international spring wheat yield nursery, 1970-1971. 107 p.
- CIMMYT annual report 1972. 151 p.
- Mejoramiento e investigación sobre triticale en el CIMMYT. F.J. Zillinsky. 78 p.
- Informe anual del CIMMYT 1972. 152 p.
- 1974**
- Third international opaque-2 maize trials, 1972-73. 40 p.
- Eighth international spring wheat yield nursery, 1971-1972. 132 p.
- Ninth international spring wheat yield nursery, 1972-1973. 133 p.
- Second and third international durum yield nurseries. 114 p.
- CIMMYT report on wheat improvement, 1973. 112 p.
- CIMMYT report on maize improvement, 1973. 74 p.
- Epidemiology of wheat rusts in the western hemisphere, Sanjaya Rajaram, Armando Campos V. 27 p.
- CIMMYT review 1974. 96 p.
- Proceedings - world wide maize improvement in the 70's and the role for CIMMYT. 393 p.
- Maize diseases, 1974. Carlos De Leon. 77 p.
- Informe del CIMMYT sobre el mejoramiento de maiz, 1973. 84 p.
- Informe del CIMMYT sobre el mejoramiento de trigo, 1973. 117 p.
- Epidemiología de las royas del trigo en el hemisferio occidental, Sanjaya Rajaram, Armando Campos V. 28 p.
- Memoria del mejoramiento del maiz a nivel mundial en la década del setenta y el papel del CIMMYT. 393 p.
- Enfermedades del maiz. 1974. Carlos De Leon. 77 p.
- Revisión de programas 1974. 94 p.
- Evaluación de avances y problemas en la obtención de especies forestales resistentes a la roya. N.E. Borlaug. 50 p. (translation).
- Evolucionar o perecer. N.E. Borlaug. 30 p. (translation).
- La productividad agricola y el problema alimentario de la población humana. R.J. Laird. 43 p. (translation).
- La producción de alimentos a nivel mundial para el futuro. N.E. Borlaug. 8 p. (translation).
- Maladies du maïs. Carlos De Leon. 77 p.
- 1975**
- The potential for increasing cereal and livestock production in Algeria. E.D. Carter. 54 p.
- CIMMYT review 1975. 104 p.

- This is CIMMYT. 46 p.
- High-quality protein maize-proceedings of the CIMMYT-Purdue symposium on protein quality in maize. 524 p.
- The Puebla Project, seven years of experience, 1967-1973. 118 p.
- India's high yielding varieties programme in wheat V.S. Vyas, 1966-67 to 1971-72. 35 p.
- Fourth international triticale yield nursery, 1972-1973. 47 p.
- Fourth international durum yield nursery 1972-1973. 60 p.
- Fifth international durum yield nursery, 1974-75. 76 p.
- Results of the first to fifth international durum screening nurseries (IDSN). 1969-1974. 72 p.
- Quality protein maize. Anthony Wolff. 16 p.
- Durum wheat: New age for an old crop. Steven A. Breth. 16 p.
- The return of medic. Steven A. Breth. 16 p.
- Some ways international research programs can assist advanced nations. E.W. Sprague. 8 p. (reprint).
- National production programs for introducing high-quality protein maize in developing countries. E.W. Sprague. 9 p. (reprint).
- The uneven prospects for gains from agricultural research related to economic policy. T.W. Schultz. 8 p. (reprint).
- Potential for improving production efficiency of cereals. R.G. Anderson. 8 p. (reprint).
- Developing agricultural research personnel. E.W. Sprague. 9 p. (reprint).
- The field support functions of the agricultural experiment station in the developing countries. C.R. Pomeroy. 16 p. (reprint).
- A comparison of maize diseases in temperate and tropical environments. B.L. Renfro and A.J. Ullstrup. 10 p. (reprint).
- Revisión de Programas 1975. 112 p.
- Este es el CIMMYT, 1975. 46 p.
- Maíz de alta calidad proteínica, Anthony Wolff. 16 p.
- Trigo duro: Nueva era para un cultivo antiguo, Steven A. Breth. 16 p.
- Preparación del personal para la investigación agrícola. E.W. Sprague. 9 p. (translation).
- Las desiguales perspectivas de ganancias de la investigación agrícola en relación a la política económica. T.W. Schultz. 8 p. (translation).
- Programas nacionales de producción para introducir maíz de alta calidad proteínica a los países en desarrollo. E.W. Sprague. 8 p. (translation).
- Una comparación de las enfermedades del maíz en ambientes templados y tropicales. B.L. Renfro, y A.L. Ullstrup. 11 p. (translation).
- La estación agrícola experimental, sus funciones de apoyo para trabajos en el campo en los países en desarrollo. C.R. Pomeroy. 16 p. (translation).
- Le potentiel de développement de la production céréalière et de l'élevage en Algérie. E.D. Carter, 1975. 72 p.

SPECIAL REPORT

EVALUATION OF THE CIMMYT WHEAT TRAINING PROGRAM

This article was written by Burton E. Swanson, assistant professor in the College of Education, University of Illinois (USA). It is reprinted from the Journal of Agronomic Education 4:85-89 by permission of the author and the American Society of Agronomy.¹

The wheat training program in Mexico is an integral part of the International Maize and Wheat Improvement Center's overall outreach program to make improved wheat technology available to farmers in all major wheat growing regions of the tropics and

subtropics. Strong national programs are an essential part of this international wheat improvement strategy, both in the process of developing and disseminating improved wheat technology, and also in dealing with the technological spin-off problems (primarily disease epidemics) that are a potential threat to the precarious food balance in densely populated nations.

When the wheat revolution began to spread beyond Mexico in the early 60's, particularly to South Asia and the Middle East, national wheat improvement programs in less de-

veloped countries were generally weak and poorly organized. Therefore, CIMMYT organized an in-service training program to help upgrade the technical skills of research personnel in these national wheat improvement programs.

Since CIMMYT began its international wheat training program in the early 60's, more than 300 participants from nearly 40 different countries have gone to Mexico for training. In late 1972, a follow-up study was initiated to determine how effective this training approach had been in meeting the job requirements of former trainees. Mail questionnaires were sent to all former trainees who had been back home on the job for at least 6 months. Of the 183 former trainees who were sent questionnaires, 134 responded (73.2 percent).² The data reported in this paper are based on this follow-up study.³

A profile of trainees selected. The major thrust of CIMMYT's wheat training program is directed toward middle-level research workers. In this section, descriptive data are presented to characterize those trainees that were selected for the in-service training program in wheat improvement.

The mean age of wheat trainees coming to Mexico was found to be 30.6 years and all but two of the trainees were males. Although CIMMYT prefers to select trainees with a minimum of a B.S. degree, it was found that 21 percent of the trainees had less than a B.S. degree when coming to Mexico. Of the remaining trainees, 58 percent had B.S. degrees and 21 percent had M.S. or Ph.D. degrees.

Several authors have indicated that agricultural personnel selected for academic training in the U.S. are often from urban areas and relatively unfamiliar with the agricultural problems of their home countries (Mellor, 1963; Wharton, 1959). Several questions were asked to learn more about

the backgrounds of former CIMMYT trainees. First, it was found that 61 percent had grown up (at least until the age of 12) in rural areas, while 39 percent indicated that they were raised in an urban environment. Of those trainees reporting, 47.5 percent indicated that their fathers were employed in agricultural occupations (nearly all were farmers, most owning their own farms); with the remainder of the fathers being employed in business (20.0 percent), government (13.3 percent), industry (7.5 percent), teaching (5.8 percent), a profession (4.2 percent), or the military (1.7 percent).

CIMMYT trainees were all employed before going to Mexico and 98 percent were associated with wheat improvement work. Trainees, on the average, had been working 6 years on the job before being selected for training in Mexico. Most trainees were actively engaged in field research work before going to Mexico (83.5 percent), with the remainder being mainly involved in field extension work (6.5 percent), laboratory or greenhouse research (5 percent), or administrative work (5 percent).

Training objectives and methodology. The training program revolves around three main educational objectives: (i) to impart to trainees the research skills and knowledge to run a wheat improvement program (ii) to encourage and develop the trainees' ability to create (synthesize) new forms of wheat technology, and (iii) to foster specific types of attitudinal change among trainees.

Technical training.⁴ The first half of the regular 8- to 9-month training program in wheat improvement largely deals with the mechanics of conducting an efficient, well-organized research program. Trainees learn all the essential research skills and techniques needed to manipulate and evaluate new forms of wheat technology. This training is accomplished through "on-the-job training" (Laird, 1972, pp. 22-24). Trainees

follow the CIMMYT wheat program through each stage of the growing season (and the varietal development process) with each task or operation first being discussed in the classroom and demonstrated in the field. After the trainee has the opportunity to practice the skill and is "checked out" to insure that he is reasonably proficient, he proceeds to help carry out each research task or operation within the ongoing CIMMYT research program.

Once the trainee learns how to conduct a research program he can give increasing emphasis to the content or the materials passing through the research program. In terms of education objectives the emphasis is on synthesis (Bloom, 1956, pp. 162-72). The job of the breeding team is to create (synthesize) new genetic lines and varieties by combining and recombining diverse types of germ plasm. To be effective and efficient in developing high yielding varieties, the trainee must learn and become increasingly familiar with the various genetic characteristics and materials he is attempting to manipulate. For example, an experienced research scientist in the CIMMYT wheat program can walk up to an advanced generation plot—and there are hundreds of such plots—and from visual inspection alone give the approximate pedigree of the line (from several hundred potential parent lines and varieties), give several reasons why the cross was made, and evaluate the visual characteristics of the line. By working side by side with experienced scientists in the CIMMYT wheat program, and by asking and being asked the question: "why?"—trainees soon begin to develop an ability and an insight into the creative process of genetic engineering.

Attitudinal change. There is a common expression used in the CIMMYT wheat training program: "The plants are talking to you, but you have to use your *eyes to hear* what they are saying." In other words,

wheat plants being grown under a variety of different conditions (both favorable and unfavorable growth environments) respond differently to those conditions. A good observer is able to detect how plants react to each of these different environmental conditions and based on the reactions, select those genetic lines with the greatest potential.

CIMMYT scientists use a similar, but somewhat controversial, selection training technique in the research training program. Some observers have criticized CIMMYT for "using" trainees to complete routine and tedious research tasks, such as inoculating segregating populations with rust spores, as part of the training program.⁶ Performing disease inoculations is a job that CIMMYT needs to have done and requires about 2 weeks of hard, back-breaking work, wading through muddy plots (many times in the rain), injecting two tillers of each F_2 plant with a syringe full of disease inoculum.

After the first morning of this activity, there is no additional technical training value to be accomplished, however, what the CIMMYT staff learns about the "trainee population" during these two weeks is important. Some trainees can disguise their displeasure for this type of work for a morning or two, but after a week or 10 days, trainees are clearly segregating in their "reaction to hard field work." Some trainees may do the work while CIMMYT staff members are nearby, but then relax under a tree when they leave (representing an attitude of "compliance," given this type of behavior). Still others may call in sick for a few days to avoid the work (noncompliance); while others are out in the plots getting the work done. CIMMYT particularly wants to identify this last group of trainees who either "identify with," or have "internalized" positive attitudes toward this type of research (Kelman, 1958, pp. 51-60). CIMMYT believes it is this last group that will begin to

Table 1.
Trainee satisfaction with the overall technical training program at CIMMYT.

Level of satisfaction	Number	Percent
Very satisfied	85	65.4
Somewhat satisfied	42	32.3
Neutral	1	0.8
Somewhat dissatisfied	2	1.5
Very dissatisfied	0	
Total	130	100.0

Table 2.
Level of training use in respondents' present job assignment.

Level of use	Number	Percent
Little or no use of training	8	6.4
Some use of training	59	47.2
Full use of training	58	46.4
Total	125	100.0
Number not responding*	5	

*This category includes four respondents pursuing graduate studies.

Table 3
Present job assignment of former CIMMYT trainees.

Job category	Number	Percent
Wheat breeder	76	58.4
Wheat agronomist	12	9.2
Plant breeder (other crops)	7	5.4
Wheat pathologist	4	3.1
Cereal technologist	6	4.6
Wheat extension specialist	5	3.8
Seed certification (wheat)	1	0.8
Experiment station manager	4	3.1
Agricultural research technician	1	0.8
University professor	1	0.8
Extension administrator	1	0.8
Administrative position (national wheat program)	5	3.8
Other type of administrative position	3	2.3
Graduate student	4	3.1
Totals	130	100.0

make up the hard core of working scientists within national wheat improvement programs.

The training program in Mexico is viewed by the CIMMYT wheat team as only the first step in a long-term process of training effective wheat research workers and building national wheat improvement programs. Because of this long-run perspective, the training program becomes both a manpower development tool for training skilled research technicians and an "early generation" selection tool for identifying potential, hard working research scientists that are oriented toward practical, problem oriented field research. Trainees are observed in Mexico and again back home on the job. Those who excel in attitude, outlook, intellectual ability and technical know-how in both working environments are identified as prime candidates for academic fellowships. By giving these individuals additional educational opportunities, it is hoped they will move into key research and leadership positions within their own national wheat improvement programs in years to come.

Results and analysis of trainee follow-up study. Trainees were asked a number of different questions to determine how they assessed the training at CIMMYT, particularly from the perspective of their present job assignment and home country conditions.

First, trainees were asked to assess the technical training considering their training and experience before going to Mexico. Seventy-five respondents (57.7 percent) indicated the technical training was very appropriate, with another 51 (39.2 percent) assessing it as somewhat appropriate. Two respondents were undecided, with only two former trainees (1.5 percent) indicating that they felt the technical training was somewhat inappropriate for their previous training and experience.

Next trainees were asked to assess the ade-

quacy of technical training considering their home country conditions. Seventy respondents (54.7 percent) indicated the technical training was very appropriate, with another 47 (36.7 percent) assessing it as somewhat appropriate for their home conditions. Three respondents (2.3 percent) were undecided, while eight (6.3 percent) trainees assessed the training as somewhat inappropriate for their home country conditions.

Finally, trainees were asked to give an overall assessment of their total training experience in Mexico (Table 1) and then to estimate how much of the training they have been able to use in their present job assignment (Table 2).

In addition to directly asking trainees to assess the training program and their level of training use, another major concern was to determine if former trainees were still working in positions where they could make direct use of their previous training. First trainees were asked to give the descriptive title of their present job assignment (Table 3). As the data indicate, a high proportion of former trainees are still working in the specific skill areas for which they were trained—particularly wheat breeding, wheat agronomy, cereal technology, wheat pathology, or wheat extension.

Former trainees were asked to name the principal crops they work with in their present job assignment. Ninety respondents (71.4 percent) indicated that they only worked with wheat and barley, while another 25 trainees (19.8 percent) worked with wheat and other crops. Three respondents said they only worked with other crops; three trainees said they no longer worked with any type of crop improvement program; and five trainees (in addition to the four graduate students) failed to respond, but presumably are not working directly with wheat improvement work.

The work performance of those trainees

actively engaged in wheat improvement work when the survey was taken (105 trainees) was measured by asking each respondent how many research experiments, replicated applied research trials, genetic crosses, and production demonstration plots he or she had completed during the main wheat growing season of 1972. As shown in Table 4, former trainees are completing a substantial number of field research activities that tend to emphasize applied or developmental types of research; particularly in the area of varietal improvement and testing.

The observed work behavior of former trainees is quite consistent with the training objectives and strategy being pursued by CIMMYT. Furthermore, based on a comparative analysis of the CIMMYT wheat training program with the International Rice Research Institute's Research Fellow-Scholar Training Program it was possible to determine that this pattern of work behavior is largely explained (at least in these two cases) by the impact of the training program itself (as an intervening variable) rather than by other independent variables, such as the personal characteristics of trainees, the types of positions held by trainees, or the types of organizations where former trainees are employed.⁶ Therefore, it is concluded that the CIMMYT wheat training program has been successful in training research workers from less developed countries to carry on active research programs aimed at producing improved wheat technology.

Notes

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Table 4.
Average number of research and production activities completed by those CIMMYT wheat trainees that were active in wheat improvement programs during 1972.

Type of activity*	Trainees conducting each activity (N = 105)		Average number of activities completed per trainee (N = 105)
	Number	Percent	
A. Laboratory or greenhouse experiments	13	12.4	1.37
B. On station field experiments	56	53.3	5.62
C. Genetic crosses	56	53.3	227.10
D. On station replicated applied research trials	65	61.9	7.24
E. On farm replicated applied research trials	44	41.9	4.74
F. On farm high yielding production plots	37	35.2	3.71

*Research activities measured in this variable were classified in the original study in terms of a general research continuum—moving from experimental research in the top categories (types A & B), through applied or developmental types of research in the middle (types C, D & E), to the demonstration of improved agricultural technology to farmers in the bottom category (Type F)—to determine which types of research activities were being emphasized by former trainees (Swanson, 1974. Training agricultural research and extension workers. p. 163-166).

Center at the University of Wisconsin. The author, when this paper was written, was a research associate in the Department of Continuing and Vocational Education, University of Wisconsin, Madison.

2/ Four questionnaires were received too late to be included in the analyses.

3/ Burton E. Swanson, 1974. Training agricultural research and extension workers from less developed countries. Unpublished Ph.D. dissertation, p. 101-187. University of Wisconsin, Madison.

4/ CIMMYT now offers four different technical training courses in wheat improvement. The original wheat breeding and improvement program has now been supplemented with courses in cereal technology, wheat pathology and wheat production (primarily for extension specialist). Since most respondents in the follow-up study participated in the original wheat training program, this course is described here. (For information on the other three wheat training programs, see Swanson. Training agricultural research and extension workers).

5/ El-Tobgy, Hassan Ali, A.B. Joshi, Vernon Ruttan and Howard A. Steppeler. 1972. Report of the

CIMMYT external program review panel. Mimeo. International Maize and Wheat Improvement Center, Mexico.

6/ Swanson. Training agricultural research and extension workers, p. 365-379.

Literature cited

- Bloom, Benjamin, S. 1956. Taxonomy of educational objectives, handbook I: Cognitive domain. David McKay Company, New York.
- Kelman, H.C. 1958. Compliance, identification and internalization, three processes of attitudinal change. *J. Conflict Resolution*. 2:51-60.
- Laird, Dugan H. 1972. Training methods for skills acquisition. American Society for Training and Development, Madison, Wis.
- Mellor, John W. 1963. Professional training in agriculture for foreign students. p. 210-235. In Irwin T. Sanders (ed.) The professional education of students from other lands. Council on Social Work Education, New York.
- Wharton, Clifton R., Jr. 1959. The U.S. graduate training of Asian agricultural economists. The Council on Economic and Cultural Affairs, Inc. New York.

1975 CIMMYT Sources and Application of Funds

	<i>in thousands</i>	
US\$ 6048		Core unrestricted income
	US\$ 1786	Inter-American Development Bank
	1785	U.S. Agency for International Development
	650	The Ford Foundation
	625	The Rockefeller Foundation
	303	Government of West Germany
	150	Government of Denmark
	110	Overseas Development Ministry (UK)
	70	United Nations Environment Programme
	10	Institute Mondial du Phosphate
	579	Administrative charges and misc. income
1756		Core restricted income
	1018	United Nations Development Program Quality protein maize, East Africa economics
	562	Canadian International Development Agency Triticale research project
	121	Inter-American Development Bank Project in Central America and Caribbean
	55	International Development Research Centre (Canada) Research on low-temperature tolerant sorghums
1419		Special projects income
	714	Ford Foundation Projects in Algeria, Argentina, Egypt, Pakistan, Tanzania, Tunisia, misc. training
	167	Inter-American Development Bank Training in wheat and maize
	128	The Rockefeller Foundation Project in Turkey, misc. training
	111	Government of Zaire National maize program
	99	International Institute of Tropical Agriculture Project in Tanzania, misc. training
	80	Training grants from 13 donors
	75	International Potato Center Regional program in Mexico
	38	U.S. Agency for International Development Projects in Nepal, misc. training
	7	International Development Research Centre (Canada) Triticale abstracts, misc. training
9223		TOTAL INCOME
7568		Core operating costs
	1638	Wheat
	1464	Maize
	856	Training
	758	Experiment stations
	428	Information services and library
	200	Economics
	105	General service laboratories
	75	Statistical services
	52	Conferences
	899	Administration
	697	General operations
	299	Indirect costs
	97	Capital acquisitions
1550		Special projects expenses
	1328	Direct expenses
	222	Administrative charges
9118		TOTAL EXPENSES
105		Reimbursements to donors and unexpended balances
9223		TOTAL EXPENSES, REIMBURSEMENTS, AND BALANCES

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Location and elevations of experiment stations in Mexico at which CIMMYT conducts research (■ stations of the Instituto Nacional de Investigaciones Agrícolas).

