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**Transferred to Tanzania during the year.
introduction

During the 6-month period ending March 1974, the staff of this center conducted a review of its own programs. Wheat scientists examined the research fields of maize. The maize staff examined the fields of wheat. The economists looked over the shoulder of both. There were seminars in the CIMMYT conference room to discuss questions of scientific method. When a significant difference of opinion arose, a staff committee was selected to negotiate a group judgement.

Out of this 6-month process, CIMMYT produced a summary of activities which is presented in this booklet. Seven issues which received substantial discussion during the period are summarized at the back of the report, under the label of Special Reports.

For background, we have added a list of the Trustees who formulate CIMMYT's policies, a staff list, and a record of CIMMYT's audited financial support for calendar year 1973.

This publication serves as a record of CIMMYT's accountability for the year under review. More extensive scientific discussion of the activities reported will appear in *The CIMMYT Annual Report on Maize and Wheat Improvement 1973*.

Haldoré Hanson, *Director general*
El Batan, Mexico
May 1974
wheat improvement
Spring bread wheats. CIMMYT is placing high priority on stabilizing yield in addition to searching for ways to reach higher yields. Developing a broad spectrum of resistance to diseases is the primary genetic method of increasing stability. One approach being used is identification and incorporation of world-wide sources of resistance, testing in nearly 70 countries with national scientists, and recirculating superior segregates through the crossing program. CIMMYT feels this is the best way to ensure incorporation of so-called horizontal resistance to diseases. A second approach is the development of multilines of the 8156 type. We distributed 285 lines for testing at 31 locations in 19 countries to provide scientists an opportunity to select suitable mixtures for national multiline varieties.

Two new bread wheat varieties, Jupateco 73 and Torim 73, were released by Mexico in 1973 from materials developed by CIMMYT and Instituto Nacional de Investigaciones Agrícolas. Jupateco 73 yielded 5 to 10 percent more than the Bluebird series of varieties. Since 1950, the yield potential of Mexican varieties on an experimental basis has increased from 3.5 to 8.0 tons per hectare. About 7500 crosses were made among spring wheats in 1973.

Spring wheat x winter wheat. Approximately 1350 successful crosses between spring bread wheats and winter bread wheats were made in 1973. For spring wheats, winter wheats can contribute greater drought resistance, Septoria resistance, increased yield, and a better range of maturity. Spring wheats can provide the winter wheats greater disease resistance and dwarfing. A program involving Oregon State University, the Turkish national program, and CIMMYT is well established. The first two are dealing with improvement of winter wheats, and CIMMYT with the spring wheats.

Durum wheats. About 4000 crosses were made in 1973. New sources of resistance to Septoria and rusts were again incorporated. Cocorit 71, a CIMMYT-bred variety, was released in Turkey as Dicia 74. About 120,000 hectares of Jori C-69, another CIMMYT-bred variety, were grown in Algeria with higher yields than local varieties. A yield of 7.5 tons per hectare was reported from Jori C-69 in Egypt. Turkey, Algeria, and Tunisia have several CIMMYT durum lines under multiplication. CIMMYT materials are shorter and have better straw strength than most tall varieties now grown. Pasta quality determinations were made at CIMMYT for the first time this year. In 1974, the crossed F1 seed will be shared with Algeria, Tunisia, Turkey, and India.

Barley. About 1300 crosses were made in 1973. Good sources of straw strength, disease resistance, and nutritional quality are being bred into hull-less types for human food and into hulled types for animal feed. Earliness to fit short frost-free periods and low moisture situations is being emphasized. Materials were distributed to 20 loca-
tions on five continents for disease screening. In 1974 the first fixed lines will be distributed.

**Triticales.** A large number of crosses were made including some 600 new tritcale combinations of rye x durum and common wheat. Over a hundred were successfully cultured and their chromosomes doubled to give new primary triticales. New sources of winter-rye germ plasm from Turkey and other countries were incorporated. Continued advances were made in grain development—the best line now weighs 76 kilograms per hectoliter (the standard test weight for wheat). The best triticales yielded more than bread wheat at high elevations in Ethiopia, Kenya, and India. Resistance to Septoria and to low pH soils seems possible. Five international conferences were held on triticale in 1973, including one sponsored by CIMMYT in Mexico.

**Germ plasm development.** High protein content with high lysine is being transferred from the bread wheats that have the best protein to bread wheats that have the best agronomic type. Branched heads, supernumerary spikelets, long head, and other possible yield-enhancing factors are being assembled in good genetic backgrounds in an endeavor to produce more productive plant types. For triticale improvement, branched heads and male sterility and restoration are being transferred by crosses with wheat. Wide crosses were made between wheat and barley and possibly between rye and barley as part of a collaborative program between Kansas State University and CIMMYT.

**Physiology-agronomy.** The factors responsible for enhanced yields were studied in many genotypes. Erect leaves seem to have an advantage in increasing heads per square meter. Artificial drought experiments were conducted on 50 genotypes with water withheld at different periods. Preliminary data suggest that winter-spring derived types have better resistance to drought. A new postdoctoral fellow studied two herbicides and the agronomy of triticales.

**Milling and baking laboratory.** The average level of carotene pigment in durum wheat in two cycles of selection of segregating materials has improved by 50 percent. About 28,000 Pelshenke tests were conducted on bread wheats. Preliminary evaluation of triticales for industrial use were made. Six trainees worked with the laboratory in 1973.

**Wheat training.** Forty-seven wheat researchers and production agronomists were trained representing 19 countries. A large number of senior scientists spent varying times at CIMMYT and there were hundreds of visitors.

**International nurseries.** The scope and variety of nurseries distributed from CIMMYT increased markedly. Some 1140 nurseries were dispatched, double the number 1 year ago.

**Outreach activities.** CIMMYT wheat staffmembers consult each year with most wheat-growing countries in Asia, Africa, and Latin America. In 1973 the staff spend over 1100 man-days on consulting trips. In
addition to travel from headquarters, CIMMYT continued in 1973 to maintain 12 wheat staffmembers in Turkey, Lebanon, Tunisia, Algeria, and Morocco. In a new development, governments of several rice-eating countries of southeast Asia requested help in introducing a wheat crop in the winter season; these requests came from Bangladesh, Burma, Thailand, Malaysia, and Indonesia.

A CIMMYT pathologist assigned to Lebanon in 1973 is organizing an early warning system for wind-borne diseases of wheat and barley in the Mediterranean and Near East region.

Conferences. An international workshop of wheat, barley, and triticale improvement was held at CIMMYT in January 1973, and the proceeding have been published.

**SPRING BREAD WHEAT**

Mexico is referred to as the home of the high yielding wheat varieties. This is partly true, but it gives too much credit to the staff in Mexico and not enough credit to the world-wide network of wheat breeders.

Crosses of spring bread wheats made in Mexico over the last 25 years have produced a series of Mexican commercial varieties with higher yield potential, and constantly changing sources of disease resistance, in order to stay ahead of new races of disease.

Table 1 lists several new Mexican commercial wheat varieties, their yield potential, and their disease rating. These varieties moved across Asia, Africa, and Latin America where breeders reselected them, re-crossed them with local varieties, and renamed them, giving rise to

<table>
<thead>
<tr>
<th>Year of Mexican release</th>
<th>Variety name</th>
<th>Year of cross</th>
<th>Yield potential tons/ha.</th>
<th>No. of Planting seasons</th>
<th>Plant height cm</th>
<th>Disease rating in Mexico 1973</th>
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<td>Stem rust</td>
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<td>1964 Sonora 64</td>
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<td>95</td>
<td>TMR TMR</td>
</tr>
</tbody>
</table>

a/ Yield potential is measured at experiment stations in Mexico, irrigated, and essentially disease free. This does not reflect international trials nor trials on private farmers' fields. b/ All varieties were resistant to all three rusts under Mexican conditions at time of release. R= resistant; S= susceptible; O= 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.
Stem rust is one of the three major rust diseases against which new resistant wheat varieties must be developed.

Unfinished tasks

The original Mexican dwarf wheats were selected under Mexican conditions and proved well adapted to Mexico, the Indus Valley of Pakistan, more generations of high yielding varieties. It is this world-wide breeding network which sustains the Green Revolution in wheat.

Mexican bread wheats have achieved an increase of 140 percent in yield potential during 25 years, under experimental conditions in Mexico. The magnitude of this progress can be seen in irrigated fields of private Mexican wheat farmers in Sonora State. But unfortunately this is not yet the picture in the wheat fields of many developing countries.
Developing countries (FAO class II) in which wheat is an important crop.

and the Ganges Valley of India. That is where the Green Revolution made its reputation. But in many other places, Mexican dwarf wheats encountered conditions different from Mexico. There are diseases different from those in Mexico, such as Septoria in Turkey and North Africa, and stripe rust in the Andean Region of South America; there are climatic conditions different from those in Mexico, requiring greater drought tolerance, cold tolerance, or heat tolerance; there are soil problems different from those in Mexico, requiring tolerance for salinity, alkalinity, or aluminum toxicity, and many others. Breeding for these conditions is under way, but further breeding is needed either in Mexico or in the host country before high yielding varieties are adapted and available to all developing countries. (CIMMYT does not release varieties: CIMMYT distributes germ plasm to national programs, and the governments which receive CIMMYT germ plasm are free to release them as varieties under local names or they may use CIMMYT germ plasm in their own breeding programs. Either way, the national programs take responsibility for what is selected and released).

Mexican wheat varieties which moved out of Mexico to Asia, Africa, and Latin America in the 1960's showed good resistance to the three rusts, but resistance to some of the rusts is now breaking down. New varieties with different genetic resistance are urgently needed. It appears that 10 years may be the longest period that a variety can withstand the constantly changing attack of the three rusts. India reports that new races of the three rusts can now attack the Mexican varieties Sonora 64, Lerma Rojo 64, Sonalika, and Kalyansona. These varieties must be replaced with new materials containing new sources of disease resistance. This is the highest priority of the CIMMYT wheat program in 1973.

CIMMYT's continuing goal is to raise the yield potential in the various wheat growing countries. The latest bread wheat variety in Mexico, Jupateco 73, is a semidwarf bred by CIMMYT and released by Mexico in 1973. Under Mexican experimental conditions this variety
has shown a yield potential 5 to 10 percent higher than any previous Mexican variety.

CIMMYT has come to the end of the gains in yield that can be derived from shortening the plant. Further gains must come from other changes in plant architecture, plant physiology, or agronomy practices.

Stabilizing resistance to rust and Septoria

New sources of resistance

In the summer of 1972, CIMMYT planted 6000 lines of spring bread wheats at Toluca in a search for new genetic sources for resistance. The 6000 lines were chosen from the world germ plasm collection maintained by the U.S. Department of Agriculture. We chose mainly landraces (historic varieties). We rated each line for disease resistance, and selected 1000 that showed good resistance to stripe rust and Septoria. Next, we planted the 1000 lines in the winter at Obregon, Sonora State, and obtained epidemic conditions for stem and leaf rust, either naturally or by inoculation. Again we rated each line for disease resistance, and from this trial we obtained 336 lines that showed good resistance to all three rusts and Septoria. Those 336 lines are now being crossed with elite parents in the bread wheat program, and recrossed to accumulate genes for resistance.

Winter wheat sources

Some of the winter wheats, particularly from southern Europe, are noted for Septoria resistance. We are crossing winter x spring wheats, and expect shortly to have new sources of Septoria resistance transferred from the winter wheats into the spring wheats.

Continuous crossing of spring wheats

In 1973 CIMMYT continued its heavy spring wheat crossing program, making 4,000 new single crosses, half in the winter season and half in the summer season. Most of these crosses involve disease-resistant parents and are designed to achieve new combinations of disease resistance. The experimental bread wheat materials which CIMMYT sends for testing in 71 wheat-growing countries are selected from this continuous stream of breeding.

Multiline based on cross 8156

CIMMYT has completed the 3-year process of developing a multiline based upon the cross 8156. The components of this multiline are now undergoing trials at 31 locations in 19 countries. Some 285 CIMMYT-derived lines and 65 from the Indian program are included in the group. This is a relatively new strategy for disease resistance in wheat. A multiline is a mixture of seeds derived from many crosses. All the parents on one side of the crosses are sister lines of an outstanding variety (in this case, varieties selected from cross 8156). All parents on the other side of the cross carry different sources of resistance to the three rusts. By mixing the seeds coming from advanced selections from these crosses, we believe that a new race of disease cannot affect more
than a small fraction of the crop in one season. If one element of the mixture becomes susceptible to a new race of disease, that element can be replaced with new seed stocks from another resistant line. Thus the multiline could theoretically last for a long time, and provide a means of stopping epidemics. Within 10 years, we would expect to have another cross, superior to cross 8156, around which we would build another multiline, and thus the stability of yields would continue.

CIMMYT holds high hopes for this new approach and so does the government of India which is collaborating with CIMMYT in producing multilines based on 8156.

Horizontal resistance is a complicated genetic form which enables a crop to resist many races of a particular pathogen, and thus to remain resistant for a much longer time. CIMMYT is using the largest range of germ plasm in the history of wheat research, and has hopes that horizontal resistance can be achieved in bread wheats (see special report on horizontal resistance).

Conclusion: A continuous breeding process

The flow of breeding material from CIMMYT to country programs and from country programs to CIMMYT provides a very wide base of parental materials for crossing by the collaborators. The net effect is a pyramiding of genes for adaptation and yield on a semi-global basis. The crossing program incorporates new sources of variability at the base of the pyramid, and the advanced generations which emerge at the top of the pyramid combine the superior genes from all the country programs.

We use many approaches to disease resistance and yield improvement. We cannot predict when the next breakthrough may come, or which of our methods will prove best. But CIMMYT and its predecessors have had steady gains over the last 25 years, and are confident that further gains will continue to appear every few years.

CROSSES OF SPRING AND WINTER BREAD WHEATS

Winter wheats (those planted in autumn, remaining dormant in winter, ripening in the summer) possess genetic qualities which the breeder wants for spring wheats, such as resistance to Septoria disease, greater drought tolerance, greater cold tolerance, and more range of maturity. By contrast, spring wheats can contribute some qualities needed in winter wheats, such as greater nitrogen response, resistance to the three rusts, and superior bread-making qualities. In addition, both spring and winter wheats represent germ plasm pools which have been little crossed in the past, and thus offer new sources of variability for many characteristics, including higher yield.
Breeders have long recognized the advantages of crossing the winter and spring wheats, which are of the same species but grow in different climates, and therefore do not normally flower in the same season. Nevertheless, in 1968 CIMMYT began a three-way collaboration in spring-winter wheat crossing with Oregon State University and the Turkish government at Ankara. A few crosses were made at each location, and the progenies were exchanged for further selection at the other locations. CIMMYT was selecting spring types from the crosses and the other two partners were selecting winter types. Progress was slow.

In 1973 a breakthrough occurred. For the first time CIMMYT found it could grow winter and spring wheats side by side, in the same crossing block at Toluca station, Mexico. Winter wheats were planted in November, spring types in January-February; both flowered in May, and ripened in July-August. Thirteen hundred successful crosses were completed. This procedure now permits the rapid transfer of characteristics between the winter and spring groups.

By moving the seed to Sonora State for the next cycle (1973-74), CIMMYT is now able to grow the progeny under spring wheat conditions, two generations a year, and should have stable spring wheats combining winter wheat characteristics within 3 years. In other words, the winter-spring progeny have become an integral part of CIMMYT's spring wheat program.

The Turkish and Oregon programs are growing the winter-spring progeny to develop winter wheats, which permits only one generation a year. Hence they will require about 7 years to produce stable varieties. They aim to produce superior winter wheats for use primarily in Turkey, Iran, Afghanistan, Korea, Algeria, and Eastern Europe. Testing in Oregon and Turkey will involve two different climates: relatively high rainfall and relatively low rainfall. Populations will be alternatively tested in one year under high rainfall and the selected plants and lines the next year under low rainfall to develop adaptation to both conditions.

To identify the best possible parents for this spring-winter crossing program, CIMMYT began re-screening the entire world collection of winter-type wheats, searching for the genetic qualities that are needed in spring wheats. During the winter of 1972-73, 2000 winter wheat items from the world collection were grown at CIMMYT's Toluca station. In the winter of 1973-74, 1000 more items are planted. The process will be completed by growing 1000 more items in the winter of 1974-75, making a total of 4000 items screened.

Not one winter wheat has so far been found resistant to the three rusts. But out of the first 2000 items screened, CIMMYT found many lines with good resistance to Septoria disease, and those items will now be used in the spring-winter crossing program.
Based upon the 1973 success at Toluca with winter-spring crosses, CIMMYT hopes for very significant changes in the spring bread wheats, especially for Septoria resistance, cold tolerance, and drought tolerance. We are particularly interested in the possibilities of drought tolerance. The ability of winter wheat to withstand low temperatures and drought appears to be controlled by much the same physiologic factors. In addition, winter wheats develop the crown root at a lower level in the soil than do spring wheats. Under low moisture conditions, the crown of the winter wheat provides a greater opportunity for the secondary root system to establish itself. This in turn enables the plant to make use of moisture from greater depths in the soil profile and also gives greater tillering, and greater above-ground development.

The greatly increased vigor of winter x spring crosses suggests that a marked yield increase can be expected from these crosses.

DURUM WHEAT

Durum wheat, the ingredient of spaghetti and other pasta products and of Arab couscous, represents 10 percent of the world wheat crop (about 30 million tons). Its production is important in the Mediterranean and Near East Region, India, North America, Argentina, Chile, and USSR.

Prior to 1968, CIMMYT’s durum breeding was directed at improvement of plant type. A backcross program was used which resulted in a narrowing of the genetic base. To enlarge variability, CIMMYT mounted a major durum breeding program in 1968 and had its 13th breeding cycle in the ground at the end of 1973. The objectives are high yield potential, broad resistance to the major diseases, yield stability, wide adaptation (ability to move between agro-climates), drought tolerance under rainfed conditions, shorter maturity for short season areas, and industrial quality acceptable to each consuming area. The resources used by CIMMYT in its durum wheat program are shown in Table 2.

Accomplishments by 1973:

- Dwarf durums resistant to lodging and with good yield potential were developed.
Selection for stable high yield is an important goal of the durum improvement program. About 4000 new durum crosses were made during 1973.

-Sources of resistance to all major durum diseases were identified, and are now used in a breeding program of 4000 crosses a year, but no single durum experimental variety yet combines resistance to all major diseases.  
-Durum nurseries from CIMMYT are being grown in over 30 countries.  
-CIMMYT breeders stationed in Tunisia, Algeria, and Turkey are full partners in this program.  
-CIMMYT’s industrial quality laboratory in Mexico is testing durum materials for macaroni-making quality.  
-The newest INIA–CIMMYT durum variety, Cocorit 71, now has yields equal to the top Mexican bread wheats and is broadly adapted. Turkey released Cocorit 71 under the name Dicla 74, and reported that this variety outyielded previous commercial varieties in Turkey by 100 percent. Cocorit 71, however, requires better resistance to stem rust, Septoria, and mildew in order to fit into the high rainfall areas of North Africa. Egypt reported a yield of 7.5 tons per hectare from Jori C-69 as compared with the highest yielding bread wheat, Mexipack, at 5.4 tons per hectare in plots in Middle Egypt. Algeria imported about 15 tons of Jori C-69 and grew about 120,000 hectares of the variety in 1972-73.

Nevertheless many problems remain to be solved.
CIMMYT’s summer testing station near Toluca is one of the best spots in the world for screening against such diseases as Fusarium and stripe rust. High moisture in a cool climate produces conditions favorable for diseases. No variety remains wholly free of disease when the Toluca station creates a maximum epidemic. Fusarium, stripe rust, and Septoria were all prominent during the trials in 1973 at Toluca. El Batan station proved better in testing for stem rust.

Most of CIMMYT’s 4000 crosses on durums in 1973 were aimed at combining the sources of disease resistance in a few durum lines, under these conditions. This a slow process.

CIMMYT makes some crosses to combine shorter maturity with better yielding and disease-resistant types. North African countries need varieties which possess a relatively long vegetative period, but which will also mature as quickly as possible after heading, because hot winds and drought in North Africa threaten any crop which prolongs the grain-filling stage. CIMMYT sends its F2 segregating populations for selection under those local conditions in North Africa.

High yielding semidwarf durums possessing some degree of cold tolerance—semiwinter growth habit—are needed for the high plateaus of Algeria, Turkey, Afghanistan, the southern part of Chile, and similar climates. Presently, durum land races with these attributes are being extensively used in crosses with the best of CIMMYT lines.

CIMMYT formerly rejected phenotypes which grew too tall in Mexico, but these materials are shorter when grown under rainfed conditions in North Africa. CIMMYT now sends tall materials for testing in early generations in North Africa, India, and Argentina.

CIMMYT requires wider variability in its germ plasm pool to solve some of the above problems. Therefore CIMMYT is adding about 250 entries a year to its germ plasm bank of 4000 durum lines. Some of the new materials are land races (historic varieties) and some are advanced breeding lines from national programs.

Formerly CIMMYT pollinated three heads of each cross, and used the seed from all three heads for research in Mexico. Now CIMMYT is pollinating four heads of each cross, and sending the F1 seed of two heads to North Africa, Turkey, and India. This will reduce the 2000 crosses per cycle to 1600, but the wheat staff believes this is the best strategy.

CIMMYT’s wheat staff is studying the feasibility of a multiline approach, using the best durum variety so far identified, Cocorit 71. A number of crosses in this direction have already been made.
Barley is eaten by about 200 million of the world's disadvantaged people in Eastern and Northern Europe, the Mediterranean and Near East region, India, and the Andean countries of South America.

The world's barley production in 1971 was 152 million tons, making barley the fourth-ranking cereal after wheat, rice, and maize. Most of the barley is grown in the temperate zone of Europe and North America for industrial malting or animal feeds. Only about 10 percent of the world crop is used for human food.

Nevertheless, barley is an important food crop because it grows better than any other cereal at high elevations in the tropics where the growing season is short and rainfall and temperatures are low, or in low rainfall areas of the temperate zone where barley is more drought tolerant than wheat. Barley's short growing season often enables it to escape a drought that would destroy wheat.

Until recently research on barley was concentrated on industrial malting and animal feed in the temperate zone. The CIMMYT program aims primarily at improving barley for human food in marginal areas.

CIMMYT's current barley program is 2-years old. Its fourth breeding cycle was in the ground at the end of 1973.

Using CIMMYT's working germ plasm collection of 5000 barley items from all continents (compared with 15,000 items in the complete
CIMMYT made 1353 crosses in 1973. The largest number were single crosses, but there were also over 300 double crosses and top crosses. The number of crosses per year will increase as CIMMYT identifies more outstanding progenitors. Crosses are being made to produce varieties of barley which combine:

- Wide adaptation, with daylength insensitivity and wide range of maturity.
- Lodging resistance, through stiffer straw and wider root structure or crown.
- High yield response to nitrogen.
- Semi-lax head to facilitate intake of radiation.
- Better resistance to all major insect pests and disease pathogens.
- Good drought tolerance.
- Improved protein percentage with higher lysine.
- Hull-less grain for human food.
- Greater yield stability.

These characteristics are all important and are not listed in order of priority. Good genetic materials have been identified for introducing most of the characteristics CIMMYT is seeking, but it will take a minimum of 10 cycles—5 years—to concentrate many of these qualities into a few plants of advanced generations which might be suitable for release as commercial varieties.

Some developments in 1973

Wide adaptation

Employing the same pattern that was used for dwarf wheats, the barley program is alternating one winter generation at sea level in Sonora State, 29°N; then one summer generation at El Batan, 2200-meters elevation, 19°N. This variation in altitude and elevation is expected to eliminate daylength-sensitive genotypes within a few cycles. Starting with the fifth cycle, this material will be tested world-wide, thus speeding up the achievement of wide adaptation.

Lodging

Barley suffers from two types of lodging, one from breaking of the straw, the other from weak root structure or crown. Japanese varieties have been found with excellent straw but weak crown. Mexican varieties have been selected with excellent crown and fairly good straw.

Developing countries (FAO class II) in which barley is an important food crop.
Enrique Rodriguez, barley breeder, and Glenn Anderson, associate director of the wheat program, take notes on some new barley crosses.

Good combinations have been found in Minnesota spring barley and Indiana winter barley. Crosses among all these varieties are now growing in the CIMMYT breeding plots.

**Better protein**

CIMMYT's working collection of barleys has been screened for gross protein and for lysine. These tests are repeated for every cross, and those which fail to show high protein and high lysine are rejected unless they have other special breeding characteristics. CIMMYT's protein laboratory analyzed the protein content of more than 4000 barley samples during 1973.

CIMMYT based its first high protein efforts on the Hiproly gene, a Swedish discovery from an Ethiopian variety, but the plant type was found to be unsatisfactory, even at the F3 stage. Now CIMMYT is employing a Danish mutant derived by irradiation of the variety Bomi. This mutant raises the lysine content by 45 percent (compared with the 30% increase given by the Hiproly gene).

**Earliness**

Very short-season barleys are needed for some climates which have a short season between spring and fall frosts, or very short rainy seasons.
Such earliness has been found in Russian varieties like Early Russian, Svalof Mari, and Svalof Mona, which flower in 40 days and bear grain in 65 to 70 days. Yield potential is low, and these varieties have other defects but crosses are now being grown which CIMMYT hopes will transfer the Russian earliness to varieties with higher yield potential.

**Nakedness**

The hull-less or naked grain in barley is preferred for human food. This character is found in some landraces of Tibet, and in many commercial varieties, and is simply inherited. CIMMYT is presently employing a Danish variety which combines nakedness and large plump kernels.

**Disease resistance**

Barley is afflicted by nearly all diseases of small grain. CIMMYT has identified resistant varieties which are now employed as progenitors. Under Mexican conditions resistance has been found for:

- Powdery mildew (*Erysiphe graminis, var. hordei*)
- Scald (*Rynchosporium secalis*)
- Spot blotch (*Helminthosporium sativum*)
- Net blotch (*H. teres*)
- Bacterial blight (*Xanthomonas translucens*)
- Loose smut (*Ustilago nuda*)
- Covered smut (*U. hordei*)
- Stem rust (*Puccinia graminis, var. hordei*)
- Leaf rust (*P. hordei*)
- Stripe rust (*P. striiformis*)
- Barley yellow dwarf virus.

At first, it was difficult to identify varieties resistant to one disease when there were simultaneous heavy epidemics of several diseases which mask each other. Collaboration with the Mexican research agency, Instituto Nacional de Investigaciones Agrícolas, has helped greatly. INIA has four testing sites for barley in Mexico, under different agro-climates, which permit differential screening of diseases. The next step will be to test in the world's "disease hot spots" the barleys which have proved resistant in Mexico.

**Training**

In 1973 CIMMYT received its first four trainees in barley research: two from Turkey, and one each from Syria and Korea.

**Current research materials**

The current winter research cycle of 1973-74 includes, besides the new crosses, 296 F2 bulks, each from a single cross; 2000 lines of F3 bulks, and 636 F4 selections.

**International nurseries**

CIMMYT distributed its first international barley screening nursery to cooperators in 20 countries on five continents in May 1973. Data from these tests should flow back to CIMMYT early in 1974. The first nursery of segregating materials will be distributed by CIMMYT in the spring of 1974.
Progress in eliminating shrivelled grains in triticale from 1967 to 1973. By intensively selecting for plump grains, breeders were able to produce lines in 1973 which equalled the standard test weight for wheat, 76 kg/ha.
TRITICALE

Triticale is a wide cross (cross between genera). Like the mule, which is a wide cross, triticale was originally sterile, until the chromosome number was doubled. And like all wide crosses among plants, triticale started with a narrow germ plasm base and shrivelled grain. It also suffered, like its rye parent, from tall straw, susceptibility to lodging (falling over), and from low yields. Each year since the Armadillo lines appeared in 1968, triticale breeding has made great progress.

History

When a history of triticale is written, the following will be among the key dates, and the year 1973 will be important for its developments.

1876. Scientific literature reported the first hybrid between bread wheat (six sets of chromosomes) and rye (two sets of chromosomes), by Wilson in Scotland. The plant had half the wheat and half the rye chromosomes and was completely sterile.

1891 onward. Scientific literature next reported the first amphiploid triticale, by Rimpau in Germany. He crossed bread wheat with rye, and found a plant in which the sets of chromosomes had doubled naturally (giving eight sets of chromosomes or an octoploid). The plant was quite sterile. Research continued for half a century, mainly in Europe, using bread wheat and rye, but the resulting plants were little more than curiosities.

1931. The name triticale appeared in European scientific literature for the first time to describe the hybrid between wheat and rye. The word is a compound of the generic names for wheat (Triticum) and for rye (Secale).

1940-1954. Two new developments permitted the use of durum wheats (two genomes) and rye (one genome) in forming hexaploid triticales. One development was the use of embryo culture. The other was the use of the chemical colchicine to double chromosomes. Most research on triticales since 1940 has centered on hexaploids.

1954-1964. The University of Manitoba (Canada) began a triticale program in 1954, aiming to develop a commercial crop. This was the first large, sustained breeding effort. Considerable progress was made in the decade 1954-64 but all the plants remained daylength sensitive and were susceptible to some diseases, particularly ergot. Yields were still considerably lower than those of bread wheats.

1965. CIMMYT joined the University of Manitoba in triticale work and by conducting research in Mexico gradually broke the daylength sensitivity, so that some triticales were able to move north and south between latitudes.

1968. Almost complete fertility was achieved in a new line of triticale by an accidental outcross in Mexico between a CIMMYT field of hexaploid triticale and an adjoining field of bread wheat (also hexa-
ploid). Only 29 fertile heads were found from this accidental cross, and the progeny of only six to eight of these heads were retained. Progeny from this new triticale were named Armadillo. Besides having fertility, the Armadillo line had one gene for dwarfing, and better plant type than any previous triticale. The bread wheat parent of Armadillo has never been identified. Since 1968 Armadillo has been crossed with other triticales all over the world and has contributed its fertility and better plant type.

1971. Triticale work was greatly speeded by Canadian government financing, both at the University of Manitoba and at CIMMYT. In 1971 the Cinnamon line, an improvement which converted Armadillo into a two-gene dwarf, brought a gain in yield. But the triticale of 1971 still had shrivelled grain, which caused lower test weight (i.e. weight of grain per hectoliter).

1972. CIMMYT set out at spring harvest of 1972 to solve the problem of shrivelled grain, and was partially successful by the following procedure. First, the staff examined the grain on 600,000 plants standing in 6000 double rows at Obregon. About 15,000 plants which seemed to have plumper grain were hand threshed. Among these, 90 percent were thrown away. This left 900 rows which still seemed superior. A mechanical thresher was brought in and 15 spikes from each of these 900 rows were threshed and examined by eye. Again almost 90 percent were rejected. But the grain from 2250 plants was retained for breeding. This selection procedure required 15 days. The plants chosen for plump grain were used to make single crosses to the elite lines of triticale in the winter season of 1972-73. The next harvest (spring of 1973) produced the plumpest triticale grain that had been seen that far in Mexico.

1973. This was a year of great progress:

- The triticale gene pool was greatly expanded by more efficient methods for making primary triticales, by crosses between winter ryes and spring triticales, by introducing rye landraces from Turkey
- Higher test weight per hectoliter
- Higher yields per hectare
- Improved cytology techniques to distinguish rye from wheat chromosomes
- Five international conferences on triticale in 1973

The cross between the durum wheat plant (four sets of chromosomes) and the rye plant (two sets of chromosomes) rarely produces viable seeds by normal fertilization, but the scientist can produce plants by embryo culture after fertilization, a delicate laboratory operation. Only about 30 hexaploid primary triticales, as these laboratory crosses are known, were available to CIMMYT before 1972. By improving the technique for making primary triticales, CIMMYT produced 125 new primary triticales in 1973 alone. The improved technique involves a change in the chemical medium in the laboratory, a change in the
growth hormone for the embryo, and introduction of a refrigeration treatment.

Another step forward was success in making many crosses between winter ryes and spring triticales, and between winter triticales and spring triticales. Winter ryes were planted in a crossing block at Toluca in October 1972; spring triticales were planted in the same crossing block in January 1973; both flowered in May, were crossed by breeders in the field, and both matured in July-August 1973. Toluca temperatures permitted the normal vernalization of the winter types. Approximately 150 successful crosses were made between winter ryes and spring triticales in this one season.

Winter-spring crosses can enrich the triticale program. Most research on rye in the 20th Century was performed in Canada, USSR, Hungary, and Sweden on winter-type rye which was daylength sensitive, and therefore adapted only to the upper latitudes. Prior to 1972, this improved germ plasm from rye was not much used in the Mexican breeding program because of the difficulty in making crosses between winter-type and spring-type cereals. Now all the improved germ plasm in winter ryes from Canada and northern Europe becomes readily
Triticale has large spikes — This one has 47 spikelets. Breeding to increase numbers of spikelets per spike may raise yield potentials.

usable, permitting a rapid broadening of the triticale germ plasm in Mexico.

A third factor enlarging the triticale gene pool was the collection of winter, spring, and intermediate rye germ plasm in Turkey in 1972 by CIMMYT. Turkey is one of the original homes of the rye plant, and contains many landraces (historic varieties) having wide variation in plant type and growth habit. This Turkish collection was tested at Toluca (1972-73) and the best of the Turkish lines are now used in the crossing program.

The standard measurement of the weight of grain is in pounds per bushel, or kilograms per hectoliter. The commercial standard for wheat is 60 lb/bu, equal to 76 kg/ha. In 1968 the test weight of the best triticale in Mexico was only 60 kg/ha, because of shrivelled grain. In 1973 the best triticale grain finally reached 76 kg/ha. The test weight of Mexican bread wheats runs higher than the commercial standard. For example, the test weight for the Mexican variety INIA 66 is 84 kilograms per hectoliter. Triticale breeders now expect the test weight of triticale to continue rising, until it reaches the level of Mexican wheat.
Higher yields

In 1968 the best yields for triticale at CIMMYT were about 2500 kg/ha compared with 6000 kg/ha then for bread wheat. By 1972 the best yields for triticale had risen to 7000 kg/ha and those for bread wheat were 8000 to 9000 kg/ha. By 1973, the best yields for triticale were at 8000 kg/ha in Sonora State of Mexico, where wheat yields were 8000 to 9000 kg/ha, and in the summer season on the high Toluca plateau (a season when diseases usually reduce yields) triticale equalled the best bread wheats.

As recently as 1971 CIMMYT had to restrict the application of nitrogen on triticale to 50 kg/ha to avoid lodging, whereas wheat was normally receiving 150 kg/ha of N in the same trials, without lodging. Now triticale can tolerate almost the same level of N as wheat.

The yield gains in triticale are mainly attributable to improved fertility and better lodging resistance. A further yield gain attributable to plumper grain and better test weight is still to come in 1974. Also the yield gains from a broader germ plasm base will show up in the yield trials about 3 years in the future.

Protein content

As shrivelled grain in triticale is being corrected, the percentage of total protein in the grain has declined, from a high of 17 percent in 1968 to about 13 percent in 1973. But the total production of protein per hectare has continued to rise:

<table>
<thead>
<tr>
<th>Best yields</th>
<th>Protein content</th>
<th>Total protein production</th>
</tr>
</thead>
<tbody>
<tr>
<td>1968</td>
<td>2500 kg/ha</td>
<td>17.0%</td>
</tr>
<tr>
<td>1971</td>
<td>7000</td>
<td>14.0</td>
</tr>
<tr>
<td>1973</td>
<td>8000</td>
<td>13.7</td>
</tr>
</tbody>
</table>

Among 2700 lines of triticale tested in the CIMMYT protein laboratory in 1973, the range of total protein was 10.7 to 16.3 percent, and the average was 13.7 percent. Commercial wheat normally contains 11.5 to 12 percent total protein, so we can say that triticale contains a similar range, or slightly better.

In lysine content, triticale is significantly better than wheat. Among the 2700 lines of triticale tested for protein at CIMMYT in 1973, the lysine level, as a percent of total protein, ranged from 2.7 to 4.4 percent, and the average was 3.7 percent. The lysine level in commercial wheat is about 2.3 percent and lysine in opaque-2 corn is about 4.3 percent. Thus the lysine level in triticale can be considered superior among commercial cereals, better than wheat, better than normal corn, and approaching the level of opaque-2 corn.

Biological assay of triticale, that is, feeding to laboratory animals to test the animals' growth response, has demonstrated that triticale has superior feeding values per unit of protein, compared with normal corn, and triticale contains more units of protein by crop weight than corn.

CIMMYT's protein chemist is using a shortcut in measuring lysine
Wider geographic adaptation

International triticale nurseries were grown in 1973 in about 40 countries, in 208 trials. These yield trials showed continuing improvement in the adaptation of triticale to a wider range of climate. Ethiopia reported that triticale outyielded the wheat checks in its national trials by a considerable margin, largely due to better resistance to *Septoria tritici* and greater tolerance to lower pH soils. Kenya reported triticale showed better resistance to the rusts than did bread wheats in its national trials, particularly to stem and stripe rust. India found that triticale showed advantage over wheats in trials conducted in the foothills of the Himalayas, under low temperatures and heavy rust infection.

Improved disease resistance

Each year CIMMYT chooses 250 parents for the triticale crossing block, on the basis of their disease resistance. The cumulative effect of this breeding is confirmed by a CIMMYT pathologist stationed in Lebanon who conducts regional disease nurseries with wheat and triticale. He

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reports that triticale consistently shows superior disease resistance to smut, Septoria, and mildew.

**Industrial quality**

Hundreds of quality tests were made on triticale grain in 1973. The CIMMYT laboratory and commercial laboratories elsewhere have found that bread, *chapatis*, and *tortillas* of acceptable quality can be made with triticale. Triticale does not now meet the bread-making standards of Canada and the U.S.A. CIMMYT is not working on this problem since CIMMYT's mandate is to serve the developing countries.

It has been found in Ethiopia that *enjera* (local bread) can be made satisfactorily when 50 percent triticale flour is mixed with 50 percent teff flour.

**Wider commercial uses**

Hungary was the first country to introduce a commercial crop of triticale for rye-type bread making, starting in 1968. Spain entered the commercial field in 1970. Contract growing of triticale for a distillery in Canada began in 1961, and the Canadian government licensed triticale for general commercial use in 1970. The U.S.A. has developed triticale since 1971, mainly as winter forage in the southwest U.S.A.

A food manufacturer at Lubbock, Texas has placed on the U.S. retail market through supermarkets, various triticale food products including bread, cakes, macaroni, and pancake flour. Argentina has introduced triticale as a commercial forage crop.

Altogether in 1973 about 250,000 hectares of triticale were planted in Europe and about 100,000 hectares of triticale in the U.S.A. and Canada. The current experimental trials in Algeria, Ethiopia, Kenya, Turkey, and India may lead to commercial use in those countries.

As in other crops, CIMMYT does not release commercial varieties of triticale, and to this time, the government of Mexico has not named or released any triticale variety bred by CIMMYT. The testing of triticales in Asia and Africa is largely from CIMMYT materials, and it is possible that one of those countries will name the first variety selected from CIMMYT breeding.

The Manitoba-CIMMYT triticale program makes no effort to promote any particular use for triticale, but is seeking by international trials to let the new crop be seen so that it will be adopted wherever it is competitive.

**Improved cytology techniques**

In 1973 important progress was made in identifying chromosome substitutions in triticale. CIMMYT is now trying to determine what combination of chromosomes gives the best agronomic performance in the crop to accelerate the development of good agronomic types. Gustafson of Manitoba detected a substitution of one pair of rye chromosomes by a pair from the D-genome of wheat in the Armadillo line, using trisomic analysis. Merker of Sweden, working at CIMMYT with
Mrs. Margarita Sosa of Mexico, proved the same substitution by a Giemsa staining technique.

When five different conferences on triticale are held in the same year, something significant must be causing interest. The conferences: July, Leningrad, USSR (sponsored by EUCARPIA); August, Columbia, Missouri (sponsored by International Wheat Genetics Congress); September, Lubbock, Texas (Texas Tech. University); October, El Batan, Mexico (CIMMYT and University of Manitoba); November, St. Louis, Missouri (American Association of Cereal Chemists). The proceedings of the University of Manitoba-CIMMYT International Triticale Symposium, will be published in 1974.

DEVELOPMENT OF NEW GERM PLASM, INCLUDING WIDE CROSSES
In 1972 one of CIMMYT's breeders began to work full time to transfer selected characteristics from one plant species to another, or to concentrate certain characteristics within one species. Among the assignments now under way:

- Concentrate in one desirable parent the genes for higher total protein and for higher lysine found within the bread-wheat germ plasm collection.
- Transfer from triticale to bread wheat more spikelets per spike, more florets per spikelet, larger grain, higher total protein and higher lysine, greater disease resistance to Septoria, Fusarium, Helminthosporium.

Branched spikes might permit higher yields because they have room for more grains. At left is a normal wheat spike (INIA 66).
- Transfer Tom Thumb dwarfness (40 cm height) and branched heads from bread wheat to triticale.
- Transfer the genes for male sterility and male restorer lines from hybrid wheat to triticale thus making possible a hybrid triticale.
- Assist other CIMMYT staff and visiting scientists with wide crosses involving wheat x barley, wheat x oats, and wheat x wild grasses.

Progress in some of these assignments was displayed in the breeding
plots at El Batan in the summer of 1973, but these assignments are long term and should not be judged season by season.

PHYSIOLOGY—AGRONOMY

In 1973 CIMMYT completed 3 years of research on physiology and agronomy of wheat.

Physiological studies

Overall, the objective of the physiological studies is to understand better the factors which control yield under both dryland and irrigated conditions and to advise the breeder on criteria for selecting plants of higher yield.

How genotypes affect yield

To study the role of genotype in yield, about 50 genotypes are grown under optimum conditions (that is, adequate moisture, adequate fertility, control of diseases). Various aspects of morphology and physiology are measured and the differences are related to yield. This study is now entering its fourth year.

In the first 2 years, 1971-72, it was concluded that triple dwarfs (released in 1970) mark the end of the benefits from reduced plant stature in wheat, and CIMMYT must look in future to other factors for increase in yield potential. In the third year, 1973, particular attention has been paid to erect-leaf types to see if this aspect of plant architecture, in combination with greater plant density, can significantly affect yields.

The genotype study was repeated on the high plateau at Toluca and El Batan in the summer of 1973 to broaden the earlier observations at sea level in Sonora State.

Environmental effect on yield

A second study on plant efficiency is based upon the manipulation of environment to determine what factors limit yield in various stages of the growing cycle. In this experiment, one of the current best wheat varieties (Yecora 70, a triple dwarf) is grown under optimum conditions (no moisture stress, no fertility stress, no disease), but is subjected to artificial manipulation of the environment, and the impact upon yield is measured. Manipulations include shading at different parts of the growing season, thinning, crowding, CO2 fertilization, leaf area reduction, or introducing heat or cold to the crop.

The principal impact upon yield by any of these manipulations proved to be associated with the number of grains per square meter, rather than with grain size. The preliminary conclusion is that the breeders should be looking for ways to increase grains per square meter, that is, the efficiency of the vegetative period in producing reproductive structures.
Sixteen genotypes grown at Obregon in the winter of 1972-73 were subjected to artificial drought by cutting off irrigation water for different lengths of time and at different stages of growth. Unseasonal rains for Obregon, one in February and one in April, reduced the impact of artificial drought, and the maximum reduction of yield was less than 50 percent compared with check plots given normal moisture.

One postdoctoral fellow is engaged in the breeding of wheat types to test the impact of various morphological or physiological characteristics upon yield. No conclusions are expected before the end of 2 years, possibly 3 years.

Plants of the variety Cajeme grown in areas with, from left, high, moderate, and low (5°C) nighttime temperatures. Plants develop too fast in high temperatures so they are stunted and develop few spikelets. Plants at left also received somewhat less sunlight than the others.
Agronomic research

A postdoctoral fellow is testing the optimum agronomic package of practices for the highest yielding wheats and triticales. It is not possible to develop in Mexico the recommended practices for other countries, but by testing the optimum practices for Mexico, CIMMYT believes it can gain general judgements on practices for other locations, and
can demonstrate the kind of field trials which should be repeated in other countries and serve as the basis for recommending local practices. Considerable emphasis is being placed on herbicide recommendations for the new genotypes.

MILLING AND BAKING LABORATORY
CIMMYT's milling and baking laboratory applies different tests to breed wheat, durum wheat, and triticale to help the breeders select the best quality of grain for making bread, tortillas, chapatis, macaroni, and so on. The laboratory tested 28,000 samples of grain from individual plants in early generations during 1973 to evaluate gluten strength.

In the bread wheat program, the number of advanced lines with good gluten quality have increased significantly in the last 2 years.

In the durum program, an important industrial characteristic is pigment content, to give macaroni a yellow tint. Within the first 2 years of selecting for this character from segregating material, the average pigment content in CIMMYT durum samples has risen from 3.8 parts per million to 5.5 ppm. This is very encouraging.

The milling and baking laboratory received six trainees in 1973 (from Argentina, Korea, Bangladesh, Morocco, Algeria) to be trained in wheat quality work.

WHEAT TRAINING
From 1959 to 1973, CIMMYT provided training in Mexico for approximately 250 wheat scientists from developing countries. Forty-seven of these were trained in 1973, each for about 9 months. This was a record number for 1 year.

Training researchers in Mexico is designed to do three things: develop the skills in field and laboratory techniques needed for genetic improvement, give experience on an interdisciplinary team, and increase the participant's understanding of agricultural development as related to wheat production. Production agronomists who train in Mexico take part of the same training as the researchers, but the agronomists also receive experience in laying out of demonstration plots on private farmers' land.

Starting in October 1973, CIMMYT employed one additional training officer for wheat, a former CIMMYT production agronomist in Tunisia.

CIMMYT continued during 1973 to rely mainly upon restricted and special grants to support its in-service training in wheat:

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US Agency for International Development 57.0  
Ford Foundation 70.2  
Rockefeller Foundation 25.0  
Inter-American Development Bank 47.0  
FAO 7.5  
International Development Research Center (Canada) 8.0  
CIMMYT core budget 25.5  
**Total** 296.7

*Governments that paid for training their own nationals*

Aspects of training which require further attention: (1) Development of national training plans which will indicate the orderly development of people to conduct accelerated research and production programs. Individuals will be identified for vocational training at CIMMYT or in-country, or for academic training elsewhere, or for some combinations of both types of training. (2) Plans for "training the trainers" at CIMMYT after national leaders are committed to in-country training. This means that agronomists from developing countries will be trained to conduct courses for other production agronomists in their home countries. (3) Plans for CIMMYT trainers to give courses in countries outside of Mexico. This has not yet been done. (4) An audio-visual training center at CIMMYT, in which a trainee can spend part-time in self-instruction in his own language. (5) A series of manuals on production agronomy research which will serve as a training tool at CIMMYT, and as a reference after the trainee returns to his home country. (6) A wheat newsletter for former trainees.

Thirty-seven countries sent wheat trainees to CIMMYT from 1971 to 1973:

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There were also 30 long-term visiting scientists, visitors, trainees, or others who participated directly in the program. In addition, several
Assembling seed for some of the 1100 wheat trials conducted in 71 countries in 1973.

hundred others visited the CIMMYT wheat nurseries in Toluca, Ciudad Obregón, or El Batan.

INTERNATIONAL NURSERY TRIALS

CIMMYT's international nursery trials for wheat were grown in 71 countries in 1973. About 75 percent of these trials are under rainfed conditions and 25 percent are irrigated. The purpose of these trials is four-fold: (1) To test new lines of wheat under widely differing conditions of daylength, temperature, moisture, diseases, insects, and soils.
In India, Frank Zillinsky consults with local scientists about their work with triticale.

(2) To obtain data that guides the breeders at CIMMYT and in cooperating national programs. (3) To help train a network of cooperating scientists. (4) To exchange the best advanced germ plasm between CIMMYT and the national programs, for use in further breeding by both parties.

CIMMYT has made progress in closing the gap between past nursery trials and the publication of results. During 1973, four nursery reports were published, and the remainder of the backlog should be published in 1974. Thereafter, publishing of results should occur not later than 6 months after receipt of data. Countries participating in the nursery program are shown in Table 3.

Aside from nurseries distributed from Mexico, important regional nurseries are distributed by FAO at Cairo, to countries of the Mediterranean and Near East; Arid Lands Agricultural Development Program, Beirut, to countries of the Mediterranean and Near East; Turkish National Program, to countries growing winter wheat in the Near East and Eastern Europe; Universities of Nebraska and Oregon State (USA), to winter-wheat growing countries of the Mediterranean and Near East region. All these nurseries share in a cooperative network for both germ plasm and data.
### Table 3. International wheat nursery trials

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### OUTREACH ACTIVITIES FOR WHEAT

CIMMYT has continued its traditional emphasis on helping national wheat programs to strengthen their research and production activities.

During 1973 CIMMYT wheat staff spent over 1100 man-days consulting with governments of wheat producing countries of Asia, Africa, and Latin America. This consultation includes participation in research planning seminars, time spent in farmers fields to observe what is holding back yields, and time spent with national policymakers discussing fertilizer supplies, grain prices, grain storage, and other policy questions.
CIMMYT sent experimental wheat nurseries for 1140 trials in 71 countries. As described earlier, these trials provide advanced germ plasm for almost every country in the world which grows more than 100,000 hectares of wheat, and for many smaller producers.

Forty-seven trainees from 37 countries of Asia, Africa, and Latin America came to Mexico in 1973 for CIMMYT training courses. CIMMYT continued its contacts with more than 200 former trainees from the same areas.

Twelve CIMMYT wheat staff members were stationed in five national programs during 1973: Morocco, Algeria, Tunisia, Lebanon, and Turkey. The Morocco project completed its 4-year contract and the CIMMYT staff was withdrawn. A new project began in Lebanon, where a regional wheat pathologist now has organized a disease warning service for more than 20 countries.

CIMMYT's staff in Turkey began consulting with countries of Eastern Europe, which welcomed an exchange of wheat germ plasm.

There is a significant new development in Eastern Asia, where traditional rice growing countries are asking for assistance to start a dry-season wheat crop. Requests have been received from Bangladesh, Burma, Thailand, Malaysia, Vietnam, and Indonesia. CIMMYT staff members have visited several countries and shipped seed.

While no CIMMYT wheat staff members are stationed in South America, the Mexico-based staff continued regular consulting calls in most of the major wheat producing countries of the Western Hemisphere.
maize improvement
Changes in organization. The maize program introduced a new staff organization and set of procedures in 1973. The new system stresses an interdisciplinary team. It provides better description for the germ plasm at each stage of testing. It enables multi-location testing to guide the selection process. The new procedures should move elite varieties more rapidly to national programs.

Germ plasm bank. The 12,000 entries in the CIMMYT bank are being cataloged and evaluated systematically to select useful materials for improving the pools and, eventually, the advanced populations.

The supervisor of the bank is devoting much of his time to wide crosses of maize. In 1973 he made 9000 crosses between maize and tripsacum, a wild relative of maize that may contribute desirable traits.

Backup and advanced units for developing superior families. Breeders, agronomists, and protection staff are now integrated in the selection process which involves alternating cycles for evaluation and recombination (crossing). The new procedures were streamlined in the last half of 1973 and the progress on yields and other traits will now be reported for each summer crop, harvested in October.

Disease and insects. The plant protection staff is making disease-insect readings in every step of breeding and selection. In 1973, this staff conducted five studies of its own, aimed at finding the most efficient ways of inoculating, infesting, and making more accurate disease and insect readings, etc.

Physiology. Four series of studies were continued in 1973 to learn what limits the present tropical maize yields, and to provide guidance to the breeders on how to break the yield barriers.

Protein improvement. Research on how to improve the quality of protein in maize (by doubling quantities of two amino acids, lysine and tryptophan) continued with 45 different populations into which the opaque-2 gene has been introduced. Little opaque-2 maize is yet grown commercially (only in the USA, Brazil, and Colombia, and in these countries only by hybrids). But CIMMYT is cooperating with many national programs in Asia, Africa, and Latin America where open-pollinated varieties are under development.

International testing. Advanced maize materials were sent to 48 countries for 289 trials during 1973.

Training. Fifty-six trainees from 25 countries received in-service training in Mexico. These courses last 6 to 7 months. Courses are offered for researchers, production agronomists, and laboratory technicians.

Many other categories of personnel visited for training or experience during 1973 including 14 master's degree candidates, 8 Ph.D. candidates in U.S., 2 Ph.D. candidates doing thesis research at CIMMYT, 8 post-doctoral fellows, 14 visiting scientists for 1 month or longer, and 40 short-term visiting scientists (1 to 4 weeks each).
Outreach activities. The staff devoted almost 700 man-days of consultation to governments in Asia, Africa, and Latin America. Ten staff members were assigned on a resident basis to six national programs during the year (Colombia, Egypt, Nepal, Pakistan, Tanzania, and Zaire).

Sorghum. Two more generations of research on cold-tolerant sorghum were completed. This work is intended to serve cool climatic areas in Latin America.

Plan Puebla. CIMMYT’s 7-year management of this experiment to find ways of raising maize yields among smallholders in Mexico came to an end in 1973. The experiment proved successful in raising yields, in developing a methodology which can be useful to other projects, and in providing training to staff for other projects. The Postgraduate College of Agriculture at Chapingo is continuing the training work in Plan Puebla in 1974, and the Mexican government is financing the local extension work.

NEW ORGANIZATION AND PROCEDURES

In 1973 CIMMYT made substantial changes in the maize program. The purpose was to achieve completely interdisciplinary staff work at headquarters; and to employ agronomic trials, disease-insect ratings and other testing more systematically in the selection of superior materials. The streamlined process should produce elite experimental varieties fitted to the needs of national programs in the shortest time, the first by 1976, and the flow of new materials thereafter should be continuous.

The changes involve: (1) Greater flow of new germ plasm from the bank to the germ plasm pools in Mexico. (2) More multi-location testing within Mexico and outside Mexico, thus moving new materials from the research station to the national programs as soon as supporting information can be generated. (3) Yield trials and disease-insect readings every second season in Mexico for all pools and populations undergoing improvement. (4) Integration of breeders, agronomists, and plant protection staff in every step of plant improvement, from the testing of raw germ plasm in the bank up to the trials of elite experimental varieties at 100 or more sites outside Mexico.

To further these purposes, the staff has been reorganized into five units:

- Bank unit (maintains and tests unproven germ plasm).
- Back-up unit (handles the basic pools undergoing improvement).
- Advanced unit (tests improved populations, superior progeny, assembles experimental varieties).
- International testing unit (distributes advanced materials outside Mexico and analyzes the results of trials).
- Training unit.
Each of these units involves the combined services of breeders, agronomists, and plant protection staff.

All breeding and testing work is now being conducted two seasons a year, the summer season devoted to evaluation (testing for yield, disease-insect tolerance, and plant characters); and the winter season devoted to recombination (breeding). In this way, no year can go by without evidence whether each pool, each population, each progeny has improved in those characters for which it is being measured.

To distribute the product of the new system more effectively to national programs, wider testing of germ plasm outside Mexico is needed. This in turn requires a stronger network of cooperating scientists and institutions. To organize the stronger network, the senior staff members of the maize program are increasing the amount of

Short maize plants can put more of their carbohydrates into grain and less into vegetative growth than traditional tall varieties.
travel to collaborating countries, where they observe the international trials and participate in planning workshops. To take up the workload at headquarters, the eight postdoctoral fellows are playing a major role in day-to-day operations. A larger flow of visiting scientists from collaborating national programs to Mexico is also strengthening the network.

Maize material which previously had been improved is now being fitted into this new procedure. Nothing has been lost.

GERM PLASM BANK AND NEW WIDE CROSSES

The collection of 12,000 accessions of maize is now the largest in the world, and fills many requests each year from institutions outside Mexico. In 1973 the bank made 44 shipments of seed to 19 countries. Since CIMMYT was created in 1966, the bank has shipped seed to 80 countries.

The principal service function of the bank unit is to provide breeders with a continuous flow of selected and classified germ plasm. To fulfill this function, the bank unit gathers new accessions, repropagates seed for viability, conducts trials to classify the bank entries, and makes wide crosses between maize and its relatives to generate new germ plasm.

In 1973 the bank added 137 new accessions, propagated 973 accessions to obtain additional viable seed, and arranged for 495 accessions to be propagated by the National Agrarian University in Peru. Thus about 12 percent of the world collection was re-grown and observed during the year.

In September 1973, 14 persons connected with maize germ plasm banks in five countries of the Western Hemisphere held a workshop at CIMMYT to formulate uniform techniques for bank management,
and to draw up a uniform data system for banks, which will assist the breeders to use the items in the banks. A pilot project is now under way to test the proposed system; the Taximetrics Laboratory of the University of Colorado (USA) serves as coordinator. This pilot project will be followed by publication of a catalog for the five banks, using standard data.

**Tripsacum garden** Since 1972 the maize bank has maintained a tripsacum garden at Tlatitzapan. Tripsacum is a wild relative of maize, found widely in Mexico, Honduras, and the southwestern USA. Tripsacum possesses a vast reservoir of potentially useful genes for breeding maize with:

- Disease-free root system.
- Resistance to diseases and insects.
- Tolerance to differences in day length and to extremes of heat and cold.
- Fast maturity (seeds mature within 3 weeks after fertilization).
Adaptation to "problem soils" such as limestone outcrops, lava flows, sterile hillsides, and rocky ledges.

- Exceptional hybrid vigor.

The tripsacum garden contains all known species of this member of the grass family, and is open for experimental use by scientists outside CIMMYT.

In the summer of 1973 the supervisor of the maize bank made 9000 crosses between maize and tripsacum, as part of a long-range program to transfer desirable genes from tripsacum to maize. The resulting hybrids have not yet been analyzed. One group of crosses, which employed an Illinois maize as the female parent and a CIMMYT tripsacum as the male, produced 199 hybrid seeds, which were replanted in the El Batan greenhouse. Wide cross breeding cannot be evaluated on a year-to-year basis, but should be viewed as a continuing experiment for 5 years or more.

Breeding and Selection: The New Backup and Advanced Units

One year ago, breeding work was stressing the selection of shorter tropical plants for better standability. Secondary objectives were disease and insect tolerance and wide adaptability. Impressive progress had been made with shorter plants over the preceding 5 years. But it was not possible to apply systematic selection for all criteria and to maize materials undergoing improvement because of the lack of interdisciplinary staff work. Moreover, there was no progeny testing on a regular basis and therefore no regular yield data, although primarily visual observations were made. In 1973 the system was modified.

Classification of Pools

Pools of germ plasm are being formed: 27 pools now have been delineated. The classification of these pools is based upon climate, length of growing season, and grain type (Table 4). The characteristics of the various climates and growing seasons which are used to classify pools are shown in Table 5. This classification of pools should permit a systematic flow of materials undergoing improvement into the more advanced steps of selection.

The Work of the Backup Unit

The backup unit now grows most of the pools twice a year at research stations in Mexico. Its evaluation phase is conducted during the summer season, using selected half-sib families. At the end of the season, the best families are identified based upon a weighted criteria for all the characters under evaluation. In the recombination phase (winter season) remnant seed from the selected families is planted in isolation,
Table 4. The backup unit: Classification of gene pools.

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*a* Average temperature minimum in highland locations is generally less than 18° C; in lowland locations, more than 18° C. *b* Whether one or more are needed depends on developments in adaptation work.

ear-to-row, to serve as the female. The male pollinator is a balanced composite of the selected families, thus accomplishing recombination. Two of three ears will be chosen from each of the selected families at the end of the recombination phase.

The recombination phase is also the time when new germ plasm is introduced. New entries of germ plasm are planted near the recombination block, to serve only as detasselled females, and the balanced male pollinator is applied. This avoids contamination of the pool with unproven germ plasm. After several cycles of evaluation, however, some new entries will be found superior to the pool, and will qualify to be made part of the balanced male pollinator, and thus be blended into the pool.

Selection criteria in the summer season (evaluation phase) include yield and yield components, disease and insect reaction, and desirable agronomic characteristics. The evaluation cycle is grown at three to four different climatic sites in Mexico.

The content of each pool changes in each recombination since recombination involves a selection for quality within the pool and the
Table 5. Rough estimates considered in classifying maize gene pools.

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<th>Maturity range</th>
<th>Altitude (meters)</th>
<th>Latitude</th>
<th>Temperature °C</th>
<th>Days to silking</th>
<th>Duration of crop growth (days)</th>
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<td>0-1600</td>
<td>0-30°N-S</td>
<td>25-28°</td>
<td>Up to 50</td>
<td>90-100</td>
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<td>0-1600</td>
<td>0-30°N-S</td>
<td>25-28°</td>
<td>50-60</td>
<td>100-110</td>
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<td>0-30°N-S</td>
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<td>60+</td>
<td>110-120</td>
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<td>Up to 70</td>
<td>Less than 130</td>
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<td>15-17°</td>
<td>70-95</td>
<td>130-190</td>
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<tr>
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<td>0-30°N-S</td>
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<td>20-22°</td>
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<td>30°-40°N-S</td>
<td>20-22°</td>
<td>75+</td>
<td>150+</td>
</tr>
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</table>

a Mean of main growing season

addition of new germ plasm which has been found suitable to add to the pool.

After each evaluation, a few of the best ears (superior families) may be sent to the advanced unit to be incorporated into an appropriate advanced population. This movement of superior families from the backup unit to the advanced unit constitutes the bridge between the two units.

The advanced unit

In the advanced unit, the improvement process continues with several significant differences from the backup unit: (1) Family structure, is now full-sib rather than half-sib; (2) crosses with unproved germ plasm are no longer made; (3) selection for the desired characteristics is more intense; fewer families are chosen out of 250 in each evaluation phase; (4) testing each season is at more sites, mostly with cooperating national programs; (5) about 10 superior families are finally identified to make an experimental variety; these are recombined and the seed increased, to be tested as a variety in at least 25 sites world-wide; (6) outstanding experimental varieties are designated after trial, to be “elite” experimental varieties and these are tested at 100 or more sites. Each national program is then encouraged to organize on farm testing, and finally, to recommend for commercial use those varieties which it finds suitable to its needs.

PLANT PROTECTION

The pathologists and entomologists have now integrated their services into the bank unit, backup unit, advanced unit, and training unit, as explained earlier. Disease and insects are now considered at all levels
Several agronomy trials in 1973 enabled the plant protection staff to observe how levels of nitrogen and plant density may affect the damage from insects and diseases. Higher nitrogen did not increase ear rot in "normal" maize varieties, but significantly increased ear rot damage in opaque-2 varieties. Stalk rot incidence was not affected by nitrogen level. In a trial of plant density at three levels (33,000, 78,000, and 113,000 plants per hectare) ear rot damage increased significantly with higher density, but there was no significant increase in earworm damage. Budworm damaged plants per unit of area increased at higher plant densities.

It is important to study the different levels of disease and insect damage under different nitrogen levels and plant population levels before national programs release to farmers the new elite varieties developed. We also think it is important to monitor changes in genetic resistance associated with production practices and plant type.
Insecticide trials

Trials continued on various chemicals, available through the commercial market, for protecting the maize crop against insects. Systemic insecticide seed dressing, or hill treatment just before seeding, have given excellent protection for the 3 initial weeks of plant growth, permitting us to retain perfect stands. This protection complemented with granular whorl treatments of systemic or non-systemic materials has given significant yield increases of 1 to 2.5 tons per hectare as compared with unprotected plots. The incidence of corn stunt was reduced substantially by the same treatment.

Fungicide trials

Potential yields and general performance of unadapted varieties cannot be evaluated in physiological studies unless the varieties are protected against foliar (leaf) diseases. Several fungicides were tested on a maize variety which is highly susceptible to foliar diseases. Some fungicides gave excellent control of leaf rust and ear rots. The test plot yielded 26 percent more than the check.
Techniques of inoculation

Studies continued on the most efficient ways to inoculate maize plants with different pathogens. These studies are necessary to enable the CIMMYT staff to conduct more accurate selection and speed up inoculations as the number of improvement pools and populations increases.

For ear rots, injecting spores about 10 days after silking proved more efficient than spray methods or toothpick application to the developing ear. Trials for Fusarium gave the same results. Stalk rot inoculations with rotting organisms provided similar reaction.

Rating systems for budworm damage

Several ways of measuring budworm damage were evaluated to determine how the staff could achieve the most accurate data with the least work. It was found that the “eyeball” method of estimating leaf damage on a 1 to 5 scale was as good as a more careful measurement of leaf area damaged. A measurement of damage in the fourth week will give the most accurate evaluation when infestation levels are medium to high. Estimating the damage in one third of a plot will give as accurate results as measuring damage to all plants in a plot.

Insect mass rearing

Artificial infestation is essential in detecting sources of resistance to insects. An artificial diet, based on opaque-2 maize, has been developed for mass rearing of lepidopterous pests of wide importance. The rearing facilities should now permit us to produce sufficient egg masses of borers and budworms to infest the maize families undergoing improvement in the advanced unit.

Raising levels of disease and insect resistance

All maize germ plasm which has been found tolerant or resistant to various diseases or insects has been assembled into four pools in the backup unit, where efforts will continue to concentrate these genetic characteristics for subsequent use in the breeding program.

AGRONOMY-PHYSIOLOGY

Maize agronomists are now servicing trials by the germ plasm bank, the backup unit, and the advanced unit. Production agronomy trials in Mexico are conducted jointly with the training program.

The physiologists are continuing their studies of maize plant growth to help define for the breeders the selection criteria for improved plants of the future. Here are some current physiology studies and their preliminary results.

Factors limiting yield

Growth patterns of three lowland (tropical) varieties and five highland varieties grown at El Batan were compared with the growth pattern of a U.S. hybrid (temperate zone) grown in the U.S. The highland varieties grown at El Batan (2240 meters) had a similar grain growth
Fall armyworms thrive on a special high protein diet. They will be used to artificially infest maize populations in resistance tests.

rate to the U.S. hybrid, but, in addition, the highland varieties had a much greater dry matter accumulation in the stem after flowering. The evidence indicates that the highland varieties would have had a higher yield if they had a larger “sink” size (capacity to store dry matter in the grain). Similarly, one lowland (tropical) variety showed about the same total dry matter as the U.S. hybrid grown in the temperate zone, but the U.S. hybrid had a much greater yield. The lowland variety lacked “sink” size. The incidence of barren plants when tropical maize is grown under higher plant density was identified as an important limitation of the storage capacity of the crop.

The breeders are now crossing the U.S. corn belt material to tropical germ plasm to determine whether the growth pattern of U.S. temperate zone maize is transferable genetically. To aid in the selection of materials with a large capacity to mobilize assimilates to the grain, we need to develop a nondestructive technique for determining sugar accumulation in the stalk.

Family trials in Mexico are now selecting the populations that show the lowest frequency of barren plants under high population density. These growth studies show that CIMMYT needs to make further studies on how to maximize the storage capacity of the crop (that is,
maximize the number of potential ears, or lateral inflorescences, which develop fully, and the number of spikelets which are initiated).

In addition to factors limiting yields, the physiologists are studying ways to manipulate grain storage in the plant.

To investigate the effect of plant population density at various plant developmental stages on the components of grain yield, two varieties were planted at 33,000, 66,000, and 133,000 plants per hectare and later thinned at three growth stages. As the density of plants rose from 33,000 to 133,000, the ears per plant decreased from 1.5 to 0.87 and the grains per plant from 680 to 303. The thinning treatments indicated that population density had little influence up to 62 days after sowing, but grain yield was greatly influenced by density from 62 days up to anthesis.

To study the adaptation to climate of 28 improved populations of maize, all 28 are planted monthly at two sites in Mexico so that their response to the various weather factors can be measured. The effectiveness of this information in aiding the identification of the most suitable materials for national program relies on the collection and the standardizing of weather data at all test sites. Characterization of regional environments in terms of moisture available for crop growth from weather data will also be useful in drought studies.

The physiologists are attempting to identify materials which are adapted to environments of limiting water by analyzing yield data from international varietal trials. If contrasting materials are identified, the probable plant processes involved can be examined.

In anticipation of these studies a trial was conducted during the 1973 summer season at El Batan to establish probable procedures. Five maize genotypes were used in the experiment to measure differences between genotypes in drought response. A genotype in which stomata (pores in the leaves and stem) remain open in periods of low moisture, thus allowing diffusion of carbon dioxide for photosynthesis and of water vapor for cooling the leaf, will consume more water, but may be a superior genotype (in terms of dry matter accumulation) in a short period of drought. By contrast, a genotype which closes its stomata during a period of low moisture will lose less moisture through transpiration, and may come out of a prolonged period of drought with less damage, and resume its growth more readily.

The resistance to water movement from the soil to the atmosphere and their relationships to the status of water in the plant were also investigated.

These studies are being continued at Tlaltizapan. Total water use by the crop is being measured and related to weather data. Such
data should also allow for the prediction of drought stress-days from meteorological data. The effects of drought stress-days and the status of water in the plant, at various developmental stages, on the growth and yield of the crop is also being examined.

Genotypes which show themselves superior in drought tolerance by these studies will require further examination for the kind of root structure, as well as the behavior of the stomata under moisture stress. These studies will continue for several years, and no single cycle of research is expected to provide dramatic conclusions.

**PROTEIN IMPROVEMENT**

Most maize protein is inferior to animal protein. A commercial crop may contain 9 to 11 percent total protein. The limiting amino acids are lysine (typically 2% of protein) and tryptophan (typically 0.5% of protein). Ideally, the two amino acids should be doubled to 4 percent lysine and 1 percent tryptophan to support normal body growth and maintenance.

Since 1964 the world has known that maize protein might be improved by the use of a mutant gene called opaque-2 (the name comes from the odd appearance of the kernel). Opaque-2 maize contains approximately 4 percent lysine and 1 percent tryptophan and thus
might solve the problem of inferior quality of protein in maize. But opaque-2 maize has serious defects: (1) Yield drops slightly because the opaque-2 maize contains a soft endosperm which weighs less than the endosperm of normal maize, (2) most consumers of maize are reluctant to accept opaque-2 maize as food because of its appearance, (3) Fusarium, ear rots, and insects cause greater damage to the soft endosperm both in the field and in storage.

Since the late 1960's, the breeders have been working to select opaque-2 populations for hard endosperm, normal appearance, resistance to ear rots, and higher tolerance to stored grain insects. In 1972 the first maize population combining opaque-2 gene with hard endosperm (at that time, 85% of the kernels were hard) was distributed for testing. In 1973, 45 groups of material of tropical, highland, and temperate origin were converted to opaque-2. Five of these groups are now being tested in international trials. The rest were merged into various pools. Also, conversion of big-seeded floury-1 to opaque-2 is under way. This is a preferred food in the Andes.

Trials in 1973 indicated that some opaque-2 populations now equal normal maize in yields in each climatic zone (that is, in the tropics, in the temperate zone, and at high altitudes).

In 1973 little opaque-2 corn was grown commercially anywhere in the world. U.S.A., Brazil, and Colombia have released opaque-2 hybrid varieties to farmers.

CIMMYT is cooperating with national programs in Pakistan, Nepal, Philippines, Zaire, Tanzania, Guatemala, and Argentina which are interested in developing open-pollinated varieties with the opaque-2 gene for their nutritional value. None of these national efforts has reached the point where the government can promote opaque-2 as a change of crop and food, but that time is rapidly approaching, perhaps within the next 2 or 3 years.

INTERNATIONAL TRIALS

International trials for maize were grown in 289 trials in 48 countries in 1973. Almost all trials are under rainfed conditions, without supplemental irrigation. The purpose of these trials is to test maize germ plasm under widely differing conditions of daylength, temperature, moisture, diseases, insects, and soils to obtain data to guide the breeders at CIMMYT and in cooperating national programs, to help train a network of cooperating scientists, and to exchange the best advanced germ plasm with the national programs for further use in breeding by both parties.

Aside from the trials distributed from Mexico, important regional maize nurseries are distributed by Centro Interinacional de Agricultura Tropical for the Andean countries of South America, by PCCMCA
Table 6. Maize international nursery trials

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<tr>
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<td>0</td>
<td>Egypt (U.A.R.)</td>
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<td>11</td>
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<tr>
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<td>0</td>
<td>North Africa</td>
<td></td>
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<td></td>
</tr>
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<td>Pakistan</td>
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<td>5</td>
<td>12</td>
<td>&amp; Near East</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Philippines</td>
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<td>4</td>
<td>2</td>
<td>&amp; Canada</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Vietnam</td>
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<td>0</td>
<td>2</td>
<td>&amp; U.S.A.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>13</td>
<td>12</td>
<td>North America</td>
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<td></td>
</tr>
<tr>
<td>Asia &amp; Pacific</td>
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<td>48</td>
<td>49</td>
<td>&amp; Europe</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>296</strong></td>
<td><strong>396</strong></td>
<td><strong>269</strong></td>
<td><strong>TOTAL</strong></td>
<td><strong>296</strong></td>
<td><strong>396</strong></td>
<td><strong>269</strong></td>
</tr>
</tbody>
</table>

(Central American foodcrop program) among the six countries of Central America and Panama, by International Institute of Tropical Agriculture to countries of tropical Africa, by FAO at Cairo to countries of the Mediterranean and Near East, and by IACP (Inter-Asian Corn Program) to countries of eastern Asia.

Germ plasm is made available to all the regional programs, and data is obtained from their trials. Hence all nurseries form a cooperative network.

The countries which have been growing CIMMYT's two principal trials (adaptation nursery and opaque trial) distributed from Mexico are listed in Table 6.

**MAIZE TRAINING**

CIMMYT offers several kinds of training or experience to scientists from Asia, Africa, and Latin America:
In-service training: generally 6 to 7 months residence in Mexico for men holding a first degree in agriculture, and under age 35.

Master's degree program, in Spanish, in Mexico.

Pre-doctoral fellows: generally 1 year in Mexico to do their thesis research under CIMMYT supervision.

Post-doctoral fellows: two years' service as an associate on CIMMYT staff.

Visiting scientists or short-term residents: mature scientists invited to spend a period of observation at CIMMYT; the term "visiting scientist" indicates those who remain from 1 month to 1 year; "short-term visitors" stay 1 to 4 weeks.

In-service training

The in-service maize program is only 3-years old, but has given training to 124 young scientists from developing countries:

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
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<tr>
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<td>4</td>
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<td>2</td>
</tr>
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<td>1</td>
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<td>1</td>
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</tr>
<tr>
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<td>2</td>
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<td>0</td>
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</tr>
<tr>
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<td>1</td>
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<tr>
<td>El Salvador</td>
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<td>3</td>
<td>0</td>
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<tr>
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<td>3</td>
<td>0</td>
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<td>6</td>
</tr>
<tr>
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<td>0</td>
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</tr>
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<td>3</td>
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<td>0</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Honduras</td>
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<tr>
<td>Mexico</td>
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<td>0</td>
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<td>1</td>
</tr>
<tr>
<td>Nicaragua</td>
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<tr>
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<td>1</td>
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<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Venezuela</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>43</td>
<td>56</td>
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</tbody>
</table>

In-service training in maize is designed to develop the skills in field and laboratory techniques needed for genetic improvement, give experience on an interdisciplinary team, and increase the participant's understanding of agricultural development.

A new feature of maize training in 1973 was the layout of agronomic trials on private farmer's fields. This work was performed by the trainees in Veracruz State during the spring season, under supervision of the maize training officer, in cooperation with the agronomists and the Mexican extension service. Individual trainees have obtained yields of 3.5 to 5.0 tons per hectare in demonstrations in an area where 2.0 to 2.5 tons are normal yields. The trainees also managed the field days at which private farmers were invited to observe the measurement of yields.

Other training

During 1973 the maize program was involved in the training of degree candidates from 12 countries, two pre-doctoral fellows from two coun-
Training in research techniques is a basic aim of the maize training program.

Trainees get experience in talking to farmers about better ways to grow maize.
tries, and eight postdoctoral fellows from six countries. Ten of the degree candidates were doing their coursework at the Escuela Nacional de Agricultura, four at Kansas State University, and five at Cornell University. There were also 14 senior visiting scientists from eight countries and 40 short-term residents from 22 countries.

An unusual feature of academic training is the interdisciplinary Ph.D. program. Such programs are now under way between CIMMYT and Kansas State University and Cornell University. In each university four to six degree candidates from Asia, Africa, or Latin America are working on related topics for a Ph.D. thesis. For example, a breeder, a pathologist, 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 will do
their thesis research together in Mexico, but receive their degrees from Kansas State or Cornell.

OUTREACH ACTIVITIES FOR MAIZE
CIMMYT continued to help national maize programs strengthen their research and production activities.

The maize staff spent about 700 man-days in 1973 consulting with governments of maize-producing countries in Asia, Africa, and Latin America. Consultation includes participation in research workshops, where plans are made for the following year; time observing CIMMYT nursery materials grown by national programs; time visiting commercial crops in farmers fields to analyze what is holding back production; time meeting national policymakers to discuss fertilizer supplies, maize prices, storage facilities, and other policy questions.

Experimental seed was provided for 289 trials in 48 countries. These nurseries provide advanced populations for almost every maize-producing country in the developing world.

In-service training was provided for 56 trainees from 25 countries, and contacts were continued with more than 100 previous trainees who have returned to national programs.

Ten members of the maize staff were stationed in six national production programs during 1973: Colombia, Egypt, Nepal, Pakistan, Tanzania, and Zaire. Work in Tanzania began in 1973. CIMMYT's staff participation in Colombia ended in 1973.

BREEDING SORGHUM FOR COLD TOLERANCE
CIMMYT's sorghum breeding stems from work begun in the late 1950's. Breeders thought sorghum would prove more drought resistant than maize at elevations above 2000 meters in Mexico and other Latin American countries, but no sorghum previously tested in Mexico had set seed above 2000 meters apparently because of low nighttime temperatures.

CIMMYT's predecessor agency obtained sorghum seed from the highlands of East Africa (Ethiopia, Kenya) which set seed on the central plateau of Mexico but was excessively late in maturity. By crossing the East African lines with short duration materials from Texas, growing the segregating populations at an intermediate elevation, and bulking the seed, new lines were created which were satisfactory in Mexico above 2000 meters.

For more than 10 years this cold-tolerant sorghum has been grown as an adjunct to the maize program in Mexico. New crosses and new selections have been tested in Canada (Manitoba and Alberta), U.S.A. (Nebraska and Oregon), U.S.S.R., France, Lebanon, Yemen, Turkey, India, Argentina, Peru, and South Africa.
A program for intercrossing by hand pollination was begun in 1973 to develop germ plasm pools selected for protein quantity and quality, disease and insect resistance, seed size and color, and head type. Segregating materials from these crosses are in the ground at Poza Rica in the winter season.

A complete set of the sorghum germ plasm collection has been sent to the International Crop Research Institute for Semi-Arid Tropics in India, the world center for sorghum.

An Indian postdoctoral fellow is now giving full-time supervision to the sorghum work, which is expected to continue through 1975 under the present restricted grant.

PLAN PUEBLA

CIMMYT gave leadership to Plan Puebla from 1967 to 1973. This project was an experiment to learn how maize production and farmer income could be increased in a rainfed environment involving 47,600 small-holders cultivating an average of 2.5 hectares per family in Puebla State, about 80 kilometers east of CIMMYT. The project planners chose the Puebla area because it typified the small landholding pattern and the lagging maize yields of more than 60 percent of Mexican agriculture and more than 50 percent of the agriculture of other Latin American countries.

Plan Puebla had other objectives beyond raising maize yields: to identify techniques for inducing agricultural change among small-
holders which could be transferred to other areas and to develop a training program at Puebla which could produce leaders for other projects. These three goals had been accomplished when CIMMYT concluded its leadership over the experiment. In 1974, the project will continue under the Postgraduate College of Agriculture, Chapingo, financed by the government of Mexico. Training continues with support from The Rockefeller Foundation. This change in sponsorship marks the transition of Plan Puebla from a research project to a development program.

A detailed history of the project for the period 1967-73 will be published in 1974. Some of the highlights:

Production results
Total maize production in the area rose about 48 percent over a 7-year period. This calculation is based upon crop measurements averaged for 1967 and 1968 (the first 2 years) compared with the same measurements for 1972 and 1973 (the last 2 years). By this calculation, average yields rose from 1.7 tons to 2.5 tons per hectare.

Nitrogen fertilizer used in the project area rose 130 percent in 7 years, from an average of 34 kg/ha to 78 kg/ha.

Both family income and family welfare showed significant improvements. A nutrition questionnaire in 1970 showed that the population in the area was already eating more meat, fish, and fruit than at the beginning of the project. Families with potable water rose from 14 percent to 21 percent during the 7 years. These changes were not the result of direct project expenditures, but reflected an improvement in general prosperity.

Measured by the methods commonly used by international lending agencies, and using conservative data, the benefits of Plan Puebla far exceed the costs (costs were approximately $1.1 millions for 7 years).

Not all the gains around Puebla during 1967-73 can be attributed to the project. Maize yields, for example, were rising in Mexico, nationally, at more than 1 percent, but at less than 2 percent, a year whereas in Puebla area they rose more than 8 percent a year. Likewise, per caput income in Mexico was rising at about 3 percent a year, but these national changes were not observable in the dryland, small farmer areas. Around Puebla, the increase in rural prosperity appears comparable to the national gains.

In conclusion, it is safe to say that Puebla project was a major factor in the production gains and social changes we have observed in that area.

Techniques which contributed to success
The Plan Puebla staff is still analyzing its experience and preparing guidelines for other projects. Already 11 other projects have been
started with similar purposes in Colombia, Honduras, El Salvador, Peru, and other Mexican states.

Four techniques helped make Plan Puebla successful. First, Plan Puebla focused on the principal crop in the area, maize. Recommendations for improved technology for maize were developed by agronomy trials in the Puebla area. The new technology consisted mainly of higher nitrogen use and higher plant population, with financial assistance from local credit agencies. No "high yielding varieties" were found superior to the local varieties.

Second, new production practices were promoted to farmers in the area by an extension staff which grew to 15 persons, including five with university first degrees (ingeniero agronomo) and 10 with secondary or technical school education. This staff was divided into five groups of three men, each group responsible for about 24,000 hectares and 10,000 farmers. This staff organized the farmers into credit groups. The staff placed demonstration plots on private farmer’s fields.

Third, an evaluation unit, consisting of one social scientist and several nonprofessional assistants, conducted a baseline survey when the project began, gathered annual statistics on crop yield, credit use, etc., and helped the project director diagnose obstacles.

Fourth, the project leader made an important contribution by “coordination,” that is, by ensuring good working relations between researchers, extension workers, credit agencies, fertilizer supply agencies, and the farmer groups.

Training

Plan Puebla organized its own 6- to 9-month training course within the project area, and also arranged a 2-year master’s degree program at the Chapingo Postgraduate College for leaders of projects like Puebla. From 1967 to 1973, 70 persons were trained for projects in Mexico and in five other Latin American countries.

Training manuals are now available for three fields: crop production practices, technical assistance to farmers, and project evaluation.

CIMMYT’s future role in small farmer projects

In the judgment of CIMMYT staff, this center has attained its objective to develop insights into the problems of small, rainfed farmers who experience higher than average risks on the Central Plateau of Mexico. The next step is to broaden that experience by observing the adoption pattern for new technology among similar farmers in many countries outside Mexico including other cultures. By these means, CIMMYT expects to enhance its ability to advise national programs, especially in developing countries where the majority of farmers are small-holders, lacking irrigation, and facing higher risks than are found in the research station.
supporting services
CIMMYT now uses eight research sites in Mexico. Four are owned by the government of Mexico (that is, by INIA, the National Agricultural Research Institute), and four are owned by CIMMYT:

<table>
<thead>
<tr>
<th>Site</th>
<th>Elevation</th>
<th>Latitude</th>
<th>Hectares used by CIMMYT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIANO—INIA</td>
<td>Sea level</td>
<td>27°N</td>
<td>85</td>
</tr>
<tr>
<td>Los Mochis—INIA</td>
<td>Sea level</td>
<td>27°N</td>
<td>2</td>
</tr>
<tr>
<td>Navojoa—INIA</td>
<td>Sea level</td>
<td>27°N</td>
<td>14</td>
</tr>
<tr>
<td>Rio Bravo—INIA</td>
<td>Sea level</td>
<td>26°N</td>
<td>1</td>
</tr>
<tr>
<td>Poza Rica—CIMMYT</td>
<td>Sea level</td>
<td>20°N</td>
<td>38 (twice a year)</td>
</tr>
<tr>
<td>El Batan—CIMMYT</td>
<td>2240 m</td>
<td>19°N</td>
<td>42</td>
</tr>
<tr>
<td>Toluca—CIMMYT</td>
<td>2650 m</td>
<td>19°N</td>
<td>67</td>
</tr>
<tr>
<td>Tlaltizapan—CIMMYT</td>
<td>1000 m</td>
<td>18°N</td>
<td>31 (twice a year)</td>
</tr>
</tbody>
</table>

In 1973 CIMMYT completed the land development at the four stations owned by CIMMYT in Mexico. This included fencing, land leveling, irrigation facilities, and drainage. CIMMYT also completed in 1973 all the agricultural buildings needed for the research stations owned by CIMMYT, with the exception of a station manager’s house at El Batan.

The CIMMYT staff again reviewed the available research land in Mexico. They concluded that land at sea level is now adequate for CIMMYT's purposes, but that experimental land on the high plateau (El Batan and Toluca) is still inadequate. The staff recommended that CIMMYT should continue its efforts to obtain from the Mexican government the 12 hectares of land at the front gate of the El Batan station.

In 1973 CIMMYT's research station manager in Mexico spent 6 weeks as a consultant to the governments of Pakistan, Turkey, and Algeria, planning specific improvements of their station management.

LABORATORY SERVICES
CIMMYT has operated three common service laboratories to help the wheat and maize programs: a protein quality laboratory, an animal nutrition laboratory, and a soils and plant nutrition laboratory.

Protein quality laboratory
The protein quality laboratory assists the breeders by measuring total protein and some amino acids in experimental lines of cereals.

During 1973, analyses were made on 8400 maize samples, 4100 barley samples, 5000 triticale samples, and 2200 wheat samples. In addition to over 7000 maize samples submitted by the CIMMYT breeding program, 1000 samples were submitted by national breeding programs in Africa and Latin America. Barley was evaluated by dye-binding capacity, a quick and simple technique which permits the selec-
Evangelina Villegas, biochemist, shows data on protein tests to Norman Borlaug, director of the wheat program.

Data on protein rests Norman Borlaug, director of the wheat program.

Seven laboratory technicians from national programs (India, Pakistan, Brazil, Peru, Thailand, Yugoslavia, and Mexico) were trained in the CIMMYT protein quality laboratory in 1973.

Animal nutrition laboratory

The animal nutrition laboratory has operated since 1971, using the meadow vole as a laboratory animal to assess animal growth when fed on different samples of maize or triticale. Data obtained in these trials were disappointing because the voles' growth did not distinguish with sufficient sensitivity between the levels of tryptophan and lysine in the different samples of feed all containing the same total protein levels. CIMMYT discontinued its vole feeding trials in 1973.

Soils and plant nutrition laboratory

The soils and plant nutrition laboratory makes chemical analyses on samples of soil, water, plant tissue, and grain. During 1973 the laboratory tested 1497 samples of soil for pH, nitrogen, and assimilable ions; 40 samples of water for pH and soluble ions; and 4150 samples of plant tissue and grain submitted by the wheat physiology section for nitrogen content.
This was the second year CIMMYT has had an economics section. The section's activities aim at developing interest and competence in farm and market research which will facilitate the development and diffusion of new technology. We seek to make recommended technologies more consistent with farmers' needs and the formulation of agricultural policy more consistent with the rapid diffusion of recommended technology by developing more information on the circumstances of the farmer and his markets. To do this, the section cooperates with agricultural scientists and with investigators in developing countries. Work is organized around three major themes.

First, what characteristics of the farm, the farmer, and agricultural policy influence the adoption of new technology in maize and wheat? In pursuing this question, CIMMYT has organized studies in eight countries (Maize: Colombia; El Salvador; Kenya, west of Rift valley; Mexico, Plan Puebla; Wheat: India, Iran, Tunisia, Turkey).

These studies are designed to serve several ends: enhance CIMMYT's capacity to counsel national programs, add to the knowledge of policymakers in national programs, contribute to indigenous capacity to do useful farm and market research, sharpen the debate on the Green Revolution.

Second, what information does a policymaker need to effectively promote the diffusion of new technology and how can this information be made available to him? Our efforts here are guided by soundings from national production programs, from farmers, and from the CIMMYT staff. Our interest emerges from the assumptions that diffusion of new technology can be influenced by policymakers, that effective policy can be facilitated by sound analysis based on good farm and market level data, that many developing countries lack adequate data and research resources for providing analysis, and that CIMMYT can sensitize policymakers to the usefulness of farm-level and market-level analysis and can assist in the development of local capacity to do such analysis. CIMMYT will not provide this analysis. Rather we seek to develop procedures which can be exploited by indigenous researchers in national programs working first with external collaborators and then alone. CIMMYT, in collaboration with others, seeks to introduce formats and procedures which, while not aiming at elegance, promise more useful results than are presently being delivered to policymakers.

To further these studies, CIMMYT is organizing several workshops for social scientists who are experienced in generating data in rural areas in developing countries. These conferences are to be held in
Collaboration between economists and agronomists

Africa, Asia, and the Near East. They are jointly sponsored by CIMMYT and the Agricultural Development Council, New York.

CIMMYT anticipates that requests for its economic counseling will emerge from programs now under way, e.g. Ethiopia, Zaire, and Tanzania.

Third, how can economists collaborate in the research and training of agricultural scientists, both at CIMMYT and in national programs? Work on this theme is motivated by the critical scarcity of agricultural research resources in developing countries. To the extent that CIMMYT can assist in identifying the minimum amount of information needed to make useful recommendations, we can contribute to reducing the research resources needed by national programs.

This work, done in close collaboration with the maize and wheat programs, is being organized around three closely related issues. The first deals with the extent to which the formulation of recommendations can be made sensitive to farmers’ goals and constraints. The second is the relation of one potential goal, the farmer’s risk aversion, to agronomic research and the formulation of recommendations. Third, recognizing that researchers exercise much greater control over the environment of their research plots than do farmers over their fields, how should these differences in control influence recommendations.

As part of this effort CIMMYT expects to develop a series of manuals which will serve as training tools in Mexico and as guides for the production agronomists of national programs. More generally, results will be distributed through the training program, through CIMMYT’s work with national economists, and through CIMMYT’s counseling with those who manage national programs.

Other research

Several other subjects are of interest. One is the way in which other social scientists, e.g. cultural anthropologists and rural sociologists, might contribute to CIMMYT. We hope to experiment with the application of these disciplines to the development and diffusion of new technology in maize and wheat.

Another relates to CIMMYT’s desire to learn more about the climatic and social circumstances under which maize and wheat are grown. We particularly wish to know the extent of area where winter, spring, and durum wheats are grown, the areas where upland and lowland maize are grown, how many farmers are involved, what climatic factors are critical in each of the world’s maize and wheat areas, where and what diseases and insects are most threatening, etc. All of these questions are relevant as CIMMYT establishes priorities for its crop research. CIMMYT has asked FAO to search its files on these questions. Thereafter it might be useful to employ an agricultural geographer to consult...
with producer countries and to refine the conclusions on what types of research at CIMMYT will benefit the largest share of crop production, or the largest area, or the largest number of farmers.

INFORMATION SERVICES

Publications CIMMYT edited, printed, and distributed 13 publications in 1973, having about 1300 pages. Many of these publications were translated into Spanish and French.

The annual report for 1972 was edited in English by June 1973; the first 100 copies were delivered to the consultative group in July 1973; but the remainder of the printing order was delayed at the printer until December. The Spanish edition will be available early in 1974.

Research publications have progressed well. A backlog in the publishing of the results of international nursery trials was partially closed, and we expect the remainder of the backlog to be eliminated in 1974.

Exhibits and other audio-visual aids The audio-visual staff mounted two major exhibits in connection with CIMMYT's two international symposia of 1973. These dealt with wheat-barley-triticale in January 1973, and triticale in October 1973. Part of these two exhibits will be integrated into a permanent exhibit in the corridors of CIMMYT headquarters to serve visitors.

The audio-visual section continued its photographic work for the wheat and maize staffs, its design work for CIMMYT publications, and its distribution of slide series and motion pictures which serve as educational tools on scientific subjects relating to wheat and maize.

Visitors service Approximately 3000 visitors were registered by the visitors service at CIMMYT headquarters in 1973, half of them individually, half in groups. In addition, a large number of visitors were received by Plan Puebla and the CIMMYT research stations where no registry is kept.

Most visitors at the headquarters are given a briefing by a staff member, often with slides, a tour of the buildings, sometimes a tour of the research plots, and they may be offered lunch. A relatively small proportion of the visitors are professional scientists requiring interviews with the CIMMYT scientific staff. Nevertheless, the work load on the scientific staff has become an impediment to the research program. Two steps were taken in 1973 to relieve the visitor load of the scientists. A member of the information staff was assigned to the research station at Obregon during April to help the wheat staff handle the large number of visiting scientists during the harvest season. And a member of the director-general's office was asked to give more time to visitors requiring special attention, and also to assist the visitors
service in scheduling visiting scientists who ask for interviews with the research staff.

The director of communications continued to serve as a consultant on communications methods in Plan Puebla in Mexico, and he made two trips to Colombia and Peru during 1973 to advise small farmer projects in those countries.

CIMMYT's headquarters library now has 2200 bound books, 5000 pamphlets, and 1100 periodical subscriptions.

During 1973 the library loaned out 4700 books, pamphlets, and periodicals, and received approximately 7200 readers in the library. CIMMYT trainees make up more than half the library users. CIMMYT continues to look upon the National Agricultural Library at Chapingo, 10 kilometers from CIMMYT, as CIMMYT's comprehensive reservoir of books, and the CIMMYT library is only a working collection. During 1973 CIMMYT borrowed 664 books from Chapingo, and sent 11 CIMMYT books on loan to Chapingo.

The staff of the CIMMYT library gives about one-quarter of their time to preparation of bibliographies for the staff, and conducting searches for requested information.
Special report: VERTICAL AND HORIZONTAL RESISTANCE TO FUNGUS DISEASES IN WHEAT

What is CIMMYT's approach in developing horizontal resistance to fungus diseases in wheat? Does CIMMYT need more funds for this purpose now? Does CIMMYT recommend more funds for other institutions now?

Introduction. Some Mexican dwarf wheats, which were introduced into Asia and Africa in the 1960's, are now becoming susceptible to individual rusts and must be replaced. The world needs varieties that carry more permanent resistance to the fungus diseases.

Vertical and horizontal resistance. The nature and performance of vertical resistance is well known. Most of the resistance to the fungus diseases of wheat, such as the rusts, has been of this type. Usually it is controlled by a single gene and has been of shortlived usefulness, although there are notable exceptions. Generally, it has been associated with host-cell hypersensitivity, resulting in death of the infected cells thus automatically sealing off the further spread of the infection. This specific type of resistance has a wide array of names including physiologic, seedling, hypersensitive, major-gene, monogenic, racial and most recently vertical resistance.

There has been considerable confusion regarding the concept of a broader type of resistance. It has been designated by an array of descriptive names including field resistance, polygenic resistance, partial resistance, generalized resistance, minor-gene resistance, tolerance, and more recently horizontal resistance. Horizontal resistance is resistance which experience and adequate testing under natural conditions have shown to confer an enduring and stable protection against a pathogen or disease. Conceptually, horizontal resistances are envisaged to be such that no natural variants of a pathogen are able to compensate for the restrictions to their penetration, development or dispersion that such resistances impose. This can usually be determined only by prolonged testing.

CIMMYT scientists take somewhat less stringent criteria for horizontal resistance. They recognize an urgent need for more permanent forms of resistance. They also recognize that commercial varieties do not need "everlasting" resistance (even if such were possible in a dynamic biological system), because any variety will be superseded by further improved varieties from the breeding programs.

Breeding for horizontal resistance. CIMMYT scientists breed and select for a number of different types of horizontal resistances capable of prolonging the useful economic life of wheat varieties, such as polygenic resistance, mature plant resistance, slow rusting, tolerance, multilines.

Polygenic resistance. There is extensive evidence that a complex of resistance polygenes (with or without superimposed hypersensitive or vertical genes) are able to provide a form of resistance which will take longer to be eroded by the changes in virulence of the pathogen.

Genetic research has established that a wheat variety which is tested in many locations and which shows low infection to a disease carries a large number of resistance genes. Such polygenically resistant varieties are now the basis of selection for the CIMMYT crossing program.

Among international testing programs which help to identify desirable parents are the U.S. Department of Agriculture International Rust Nursery, CIMMYT's wheat
screening nursery, the Near East Regional Disease and Insect Screening Nursery, and CIMMYT's Latin American Disease and Insect Screening Nursery. These trials serve two purposes: they signal changes in the pathogen and they identify varieties with broader resistance which can be added to the crossing program.

An integral part of CIMMYT's wheat breeding program is the inter-crossing of large numbers of varieties and hybrid selections from programs throughout the world (5000 different crossing combinations are made annually). A high percentage of this parental material has been chosen for its disease resistance characteristics.

Single and multiple cross combinations are made to produce segregating populations containing individual plants and lines with complexes of genes resistant to many diseases.

The segregating material is subjected to a severe screening process to identify lines with superior horizontal resistance characteristics. This screening process includes, in Mexico, individual plant inoculation with a mixture of rust strains (about 2 million individual plant inoculations in each of two generations per year); inoculation of plants or soil with Septoria; testing all parental material and some segregating material in the greenhouse by seedling and adult-plant inoculation with rusts. In collaboration with scientists in 71 countries, bulk F2 populations are tested at 215 sites; segregating F3-F7 lines at 117 sites; elite selections at 20 sites; Septoria-resistant material at 25 sites; and varieties at 116 sites. These figures apply only to bread wheat. Durum wheat, barley, and triticale are tested by a similar network of world scientists.

Through this extensive testing CIMMYT wheat varieties at all stages of development are subjected to attack by a wide spectrum of diseases and races of diseases. Only lines possessing polygene resistance will resist specific diseases throughout the world.

Experience has shown that it is difficult to combine a high degree of resistance to many diseases plus select for high yield and desirable agronomic characters. A few lines with these characteristics are currently under test.

For the past 3 years, a disease early-warning surveillance network has been in operation in collaboration with the Arid Lands Agricultural Development Program (ALAD) in Beirut. It consists of a trap nursery composed of the principal commercial varieties of the Eastern Hemisphere countries, which is grown from India to Morocco. The purpose is to provide an early warning of the increase in virulence of diseases on these varieties, thus allowing an opportunity for a change of variety in commercial production.

Coupled with the extensive screening mentioned above and a Regional Disease and Insect Screening Nursery monitored by ALAD, this provides the basic defense against a sudden widespread disaster caused by disease. A similar regional project was initiated in Latin America during 1973.

Mature plant resistance and slow rusting. Some wheats are susceptible to rusts in the seedling stage, but are resistant as adult plants. There are two types of resistance that can account for adult-plant resistance: plants which develop only resistant pustules producing few spores, and the "slow rusters," which have susceptible pustules, but the disease is slow spreading and does not develop a widespread attack until so late in the season that it does not reduce grain yield significantly. Both types of resistance affect the epidemiology of the disease, reducing its damaging effects.

Several plant characters may interact to effect a high degree of horizontal resistance, based on slow rusting. Such resistance to
rust may involve exclusion of fungus, limitation of pustule size without hypersensitivity, or, possibly, slow growth and development of fungus. Characters such as these are the elements involved in slow rusting observed by many scientists. CIMMYT selection criteria does not discard a slow rust in the F2 population. These plants are regrown in further generations to re-check their slow rusting character.

In most instances, the resistance is horizontal in nature because it controls many races of the disease.

CIMMYT scientists continue to select for these types of resistance and reincorporate them into the breeding gene pool.

Tolerance. Because of the world-wide testing of CIMMYT breeding material for yield as well as disease resistance, it has been possible for CIMMYT scientists to identify some lines which, although susceptible, are little affected in yielding ability.
The genes responsible for this tolerance are also fed back into the breeding gene pool. No commercial varieties are now in use with this type of resistance as their only defense against disease attack.

Multilines. As originally conceived by Dr. N. E. Borlaug in the early 1950's, a multiline was a variety developed by mechanically mixing seed from many different backcrosses of a particular variety. Each individual line had a different form of disease resistance obtained by backcrossing to a different resistant parent. By mechanically mixing these lines, a population is formed in which there is variability from plant to plant with regard to disease resistance. Other varietal characters are maintained constant. Should one form of resistance break down, the percentage of infected plants would be small, thus avoiding an epidemic.

During 1971-73 CIMMYT and some of the cooperating national programs have made an organized effort to develop a multiline based on the complex of varieties arising from the widely adapted high-yielding cross 8156. These varieties are known as Mexipak and Indus (Pakistan), Kalyansona and PV 18 (India), Siete Cerros and Super X (Mexico), Espigas (Turkey), and Laketch (Algeria). Among these lines, different sources of disease resistance have been incorporated in several national programs, and at CIMMYT.

In the CIMMYT breeding program, all the 8156 types have been systematically selected from all generations and placed in a separate 8156 multiline nursery. These have undergone exposure to all existing Mexican strains of the three rusts and Septoria tritici. The nursery now contains more than 200 lines. During 1973, 31 sets of these lines went out to collaborators in many different countries for exposure to prevalent strains of disease in a broad geographic area. By this means it will be possible to establish which lines have usable resistance in different regions. Aliquot mixtures can then be made up for each region.

No attempt is being made to maintain exactness of the 8156 type for agronomic characters. The lines are coming from the normal breeding program with no backcrossing to regain the exact 8156 type. Within a mixture all will generally resemble 8156 in type by having approximately equal maturity, height, chaff color, and seed color.

It is necessary to grow all of the lines each year as individual lines. As one or more become susceptible to disease, they are removed and replaced by new ones with resistance before making up the new seed supply.

In Mexico, CIMMYT is working on multilines in two other series which have demonstrated broad adaptability. These are the Pitic-sib and Anza lines.

Only two multilines were developed in wheat prior to cross 8156, and only one of these entered commercial production. Miramar 63, a Frocor-based variety was developed and grown in Colombia more than a decade ago. It still maintains its overall resistance to this day. A second multiline was developed based on Gabo 56 in Mexico which was due for release in 1961. However, the dwarf varieties came along at the same time and their higher yield made this multiline obsolete even before it was released.

There is speculation on how disease resistance expresses itself in a multiline. As a general rule, vertical resistance delays the start of an epidemic, and horizontal resistance slows down the progress of an epidemic after it starts. This is true of all three rusts (Puccinia recondita, Puccinia graminis tritici, and Puccinia striiformis).
CIMMYT's observation on the performance of the 8156-multiline suggests that it operates with both vertical and horizontal resistance, that it first slows the onset of an epidemic and it later slows the course of an epidemic, and that it combines many sources of vertical resistance, thus causing a slow rate of infection, hence horizontal resistance.

Conclusion. CIMMYT and its network of collaborators have a world-wide coordinated research project on horizontal resistance to wheat diseases. It is a broad effort in terms of germ plasm, types of resistance, and cooperating manpower. CIMMYT wheat scientists recommend support for further fundamental work to elucidate the basis of horizontal resistance to wheat diseases. The best work known to them at the moment is being conducted at the Plant Breeding Institute, Cambridge, England.

Special report: RADICAL RESEARCH, AND CIMMYT'S ROLE

Does the world food outlook require a form of research more radical than the "conventional" approach which CIMMYT now uses for maize and wheat? If radical research is needed what should be the roles of CIMMYT and of universities and other research institutions in North America, Western Europe, and elsewhere? What are the next steps?

Introduction. Nearly all maize and wheat breeding in the world today is of the conventional type, that is, two plants of the same species are crossed sexually (pollen from one plant is applied to the emasculated flower of the other) giving variable progeny. The breeder then selects among the progeny for desirable characteristics. Conventional breeding has been going on for more than a century. Such breeding gives variability for plant architecture, disease resistance, yield, nutritional quality, and other economic characteristics which can help the human food supply. Progress is still possible.

The CIMMYT staff believes that continued conventional breeding will permit the world's producers of maize and wheat to stay ahead of population growth for the next 20 to 30 years. During that period, population will double and so will the production of maize and wheat. But CIMMYT has no confidence that conventional breeding will enable the world to feed itself with today's crops after the next doubling of world population (say, beyond 2000 A.D. and beyond a population of 7 billions).

To produce a further quantum leap in production of maize and wheat beyond 2000 A.D. will require some form of "radical research," that is something outside the limitations of conventional breeding. One possibility is for the plant breeder to introduce new variability into the existing crop species; a second possibility is to create completely new crop species. Both can be achieved by crosses between plants from different cereal crop genera (for example between wheat and barley), between more widely differing cereals (wheat and maize), or between plants of different botanical families (for example between a cereal like wheat and a legume like soybean). All these examples are called "wide crosses."

Scientific background. The plant kingdom has taken a multitude of pathways as it has evolved from single-celled water
plants (algae) to plants that reproduce by spores (such as ferns), then to plants with flowers with reproduction by pollen and ovules, the latter ripening into seeds.

Among plants with seeds two major subdivisions evolved: plants with a single seed leaf (monocotyledons such as the grasses, orchids, lilies, and sedges), and plants with two seed leaves (dicotyledons such as legumes, roses, poppies, and oak trees).

The embryo of a wide cross must be cut out of the kernel before it is grown in culture media.
The evolution of diverse plant types did not end there, however, it proliferated into a large number of different groups of plants that man has classified according to the degree of similarity of morphological, physiological, and, more recently, genetic characteristics. As an example, all of the grasses have been classified into a single family (Gramineae), which is made up of a large number of genera. Each genus is composed of a number of species, a grouping of grasses that look very similar and that will breed freely between themselves.

Maize, sorghum, wheat, barley, and rye are all members of the grass family; however, each of these crops belongs to a different genus. Within each genus, there are several species. In wheat there are many. The bread wheats belong to one species (Triticum aestivum) and the macaroni wheats belong to another species (Triticum durum).

Plants have taken millions of years to evolve into this wide array of species. During this time, protective mechanisms have also evolved to safeguard the genetic integrity of the species. These mechanisms, which may be morphological, physiological, or biochemical, enable the plants to discriminate between related and unrelated pollen grain during the reproductive cycle. Thus, although wheat and orchids are both monocotyledonous plants, they come from very different families and are completely incompatible sexually.

These systems of genetic discrimination are efficient but not perfect. Many studies of different plant families, in nature and experimentally, have indicated a small "leakage" of genes by cross pollination from one species or genera to another. But, the amount of introgression of alien germ plasm from one species or genus to another, usually depends on the closeness of the relationship between the parental plants. There is sometimes a small amount of genetic interchange between species or genera within a family, but seldom, if ever, interchange between plants from completely unrelated families, for example wheat and soybean.

The actual barriers to crossing vary considerably, but by far the most important appear to be biochemical. That is, there are chemicals in the style (female tube leading to the ovary) that are highly specific to particular species of genera. These chemicals stimulate related pollen to germinate and effect fertilization, but inhibit the germination or growth of alien pollen. In nature, these barriers to genetic interchange between unrelated plants are obviously important for the continued survival and evolutionary development of the species. To the breeder whose role is to direct and speed up the evolutionary process, these barriers with few exceptions have frustrated his attempts to transfer desirable traits even between related genera. For this reason, most of his work has been confined to creating new combinations of genetic variability by crossing within individual genera or even species.

CIMMYT scientists believe that a much wider range of genetic variability than presently exists in our important crop species, will be necessary to allow the plant breeders to continue improving crop yields beyond the next 20 or 30 years. And recent new developments indicate a wide cross program is now more feasible than previously thought.

**Triticale progress.** The best known and most extensive program of wide crossing is that involving the development of the new man-made genus of triticale—wheat x rye.

Together with scientists from Canada and a number of other countries, CIMMYT has been instrumental in developing this intergeneric wide cross into a new crop
CIMMYT now has the most extensive experience in the world for introgressing primary wide hybrids (triticales) into a large plant breeding gene pool. CIMMYT is currently growing 20 hectares of triticale in its breeding nursery. CIMMYT also sends triticale breeding material to 52 countries around the world.

New chemicals for wide crosses. A number of techniques have been used in attempts to produce hybrid plants from related and unrelated genera. Several have involved the use of microsurgical techniques to graft the style from the male parent onto the female parent in place of its natural style. This procedure is designed to replace the inhibiting chemicals of the female with the stimulatory chemicals from the pollen parent. The technique is tedious, difficult, and has had very limited success.
Some scientists are attempting to bypass the sexual process and use instead new techniques for growing separated plant cells in an artificial culture medium. Cells from different genera are grown together in the same medium. The cells walls are dissolved with the enzyme cellulase and then reconstituted in the hope of trapping the nuclei of two cells, one from each genus, in the same cell. The cells would then be stimulated to grow into a plant. No new genus has yet been created by this method.

During the past 2 to 3 years, Dr. Lynn Bates of Kansas State University has been working on the biochemical basis for cross compatibility in wide crosses. He has postulated that stereo-specific inhibition reactions, similar to the immunochemical mechanisms in animals, govern the barriers to crossability. In collaboration with CIMMYT wheat breeders, Dr. Bates tested several immunosuppressant chemicals, E-amino caproic acid (EACA), chloramphenicol, acriflavin, salacylic acid, and gentisic acid, with varying degrees of success. EACA appeared to be most effective, however all gave the desired response.

The chemicals were injected daily into the leaf enclosing the cereal spike, starting before egg cell division and ending at the time the anthers were emasculated to prevent self pollination.

During 1972, attempts to cross wheat and barley using one application of EACA were compared with crosses using no chemical treatment. From the treated plants, a few poorly developed seeds were obtained with embryos that produced a short-lived weak plantlet on artificial media. Although no hybrid plants survived, the trial was encouraging.

In both the winter and summer plantings in 1973, large numbers of crosses were made using chemically treated and untreated plants. Potentially viable seeds were obtained. For example, from the winter sowing, 2000 heads were pollinated, from which 171 potential hybrid embryos were recovered.

By July 1973, 74 plants had been germinated from the cultured embryos. They were from the wide crosses durum wheat x barley, bread wheat x barley, and Einkorn wheat x barley, barley x rye, barley x triticale, bread wheat x rye, triticale hexaploid x bread wheat, triticale hexaploid x rye (control), and durum wheat x bread wheat (the last cross is not difficult to make). Although many of the plants were weak and did not survive the cold treatments to stimulate tillering or the treatment with colchicine, by October 1973 there were over 300 second generation plants from the crosses bread wheat x barley (92 plants), durum wheat x barley (187 plants) and barley x rye (59 plants).

The summer crossing produced the three original combinations shown above plus oats x barley.

This research, though in its infancy, offers exciting promise for removing the barriers to crossability between widely different species or genera.

New staining technique. A new technique for staining chromosomes has been developed by a Russian cytologist who named it the Giemsa stain. The staining technique has been refined and used in a number of laboratories in countries including Sweden, England, and the USA.

The Giemsa technique allows the cytologist to identify individual chromosomes from different species and genera. For the first time it has been possible to accurately identify how many wheat and how many rye chromosomes there are in particular lines of triticale. This information is invaluable as an aid to the breeder, because it helps him select genetically stable plants for his breeding program.
Dr. A. Merker, who helped to refine the Giemsa technique in Professor Munting's laboratory in Sweden, is now using the technique at CIMMYT where he is a postdoctoral fellow.

Wheat × Agropyron—Agrotriticum. For several years, CIMMYT wheat scientists have been breeding an intergeneric cross—wheat × Agropyron elongatum. This hybrid has large plump grain and some of the lines have excellent disease resistance originating from the Agropyron, which is a member of the grass family and a wild relative of wheat.

Maize × Tripsacum. As a part of its germplasm collection, CIMMYT has assembled and maintained a garden of Tripsacum species, which is a wild relative of maize. CIMMYT now has representatives of all known species of Tripsacum. Most of the species are perennial and are maintained as live plants.

During 1973, Dr. Mario Gutierrez of the CIMMYT staff made 9000 crosses between maize and Tripsacum from which he obtained about 72,000 seeds. These have not yet been screened to determine how many are viable. As with most wide crosses, the potentially viable embryos will have to be excised and artificially cultured. Those that grow will be treated with colchicine to induce some fertility by doubling the number of chromosomes.

It has been the general experience of scientists making wide crosses that certain varieties of each species or genus will combine with each other, where other varieties will not. Also, some species will cross when used as the female parent, whereas they will not cross if used as the male parent. It was to distinguish those species and varieties that „nicked“ well in crosses between maize and Tripsacum that Dr. Gutierrez made so many cross combinations. When the data on viability of particular combinations are available, it will be possible to make fewer crosses, but with a greater chance of success.

Potential benefits from wide crossing. CIMMYT scientists are concerned about variability for future exploitation in their breeding programs. By intercrossing different genera of cereals there is the possibility of creating completely new crop genera, such as Triticale, or greatly expanding the range of variability available to the breeders for “assembling” new varieties of conventional crop species.

Bread wheat × barley. Bread wheat is itself a multiple wide cross which was formed in a wild state a long time ago. There is evidence of its existence in the Neolithic Period (2300-300 B.C.). Modern genetic studies indicate that it had as progenitors Triticum monococcum, Triticum speltoides, and Aegilops squarrosa. Each progenitor contributed seven pairs of chromosomes to the total of 21 pairs of chromosomes.

Barley has seven pairs of chromosomes. When crossed with bread wheat, the hybrid would be expected to have 28 chromosomes. When doubled by treatment with colchicine, there would be four pairs of seven chromosomes. Each chromosome will tend to pair with its counterpart within a set, thus providing a reasonable chance for a fertile hybrid.

Top, an embryo resulting from a cross between wheat and rye placed on media. Middle, growth after 3 weeks. Bottom, growth after 4 weeks. The plantlet is allowed to grow on media for about 6 to 8 weeks until both roots and shoots have developed. Then it is transplanted in soil and allowed to grow for another month or so before it is treated with a chemical to double its chromosome number in order to create a fertile plant.
Barley is the most widely distributed of the cereals. It is grown near the Arctic Circle and at the equator. Some of the spring types mature in as little as 60 to 70 days. The crop is particularly well adapted to hot, dry conditions. All of these features would be valuable to extend the adaptive range of wheat, particularly to the marginal areas of crop adaptation where many people eke out an impoverished existence.

Wheat and barley have very different forms of endosperm protein. The blend of these proteins may improve the nutritive quality of wheat protein, particularly if the high-lysine lines of barley were to be used in the cross. At present, however, the likely chemical composition of the grain cannot be predicted.

Bread wheat and oats. The main cultivated form of oats is *Avena sativa* with 21 pairs of chromosomes. It is likely that the cross combination of bread wheat and oats would be cytologically unstable with both parents having 21 chromosome pairs. Any genetic similarity between parts of chromosomes could lead to irregular pairing.

Oats are a source of well-balanced protein. The blend of wheat and oat protein may be of value as a quality food.

The grain-bearing structures of wheat and oats vary significantly. Wheat has a compact head while oats has its seed borne in a loose panicle (that is, its axis is divided into branches each bearing several seeds). These differences could provide a unique opportunity to vary the architecture and consequently the yield potential by crossing these two crop genera.

*Bread wheat and *Agropyron elongatum*. *Agropyron* species have been crossed with wheat on several occasions. Various techniques have been used to transfer parts of chromosomes to wheat to use the high level of disease resistance possessed by the *Agropyrons*. The aim of breeders has been to recapture the characteristics of wheat plus the disease resistance of *Agropyron*.

For several years CIMMYT has been breeding and selecting among a population of wheat x *Agropyron elongatum* hybrids that exhibit a blend of characteristics from both parents. Of particular interest is the high resistance to rusts and the large amber seeds produced. Attempts are being made to intercross these plants to triticale to improve the seed characteristics of that crop.

*Maize x Tripsacum*. A number of crosses between maize and tripsacum have been made at CIMMYT and other institutions.

Tripsacum has much to offer maize in hybrid combination. For example, Tripsacum has a more adequate root system than maize which effectively supports the plant in light or heavy soils and under conditions of minimal to excessive rainfall.

Various corn diseases are rarely seen on Tripsacum, even when located near infected maize fields.

Exceptional tolerance to differences in daylength and extremes of temperature are found among Tripsacum species with widespread distribution in both temperate and tropical areas.

All of these characteristics, if transferred to maize, could open new horizons for maize production.

*Maize and sorghum*. Attempts to cross maize (chromosome number, 10) and sorghum (chromosome number, 20) by scientists at several institutions have been unsuccessful. After working for 2 years, 1970-1972, a research group at Iowa State University concluded that "from these results it is difficult to draw definite conclusions about the feasibility of producing maize x sorghum hybrids through the sexual process." They reported that "pollen growth studies indicate that pollen from one genus rarely germinates on stigmatic tissue of the other genus."
This is an excellent area for attempting the use of the immunosuppressant chemicals. Grain sorghums are able to produce high yields where rainfall is insufficient and temperatures too high for satisfactory maize production. The water requirement per pound of dry matter produced by sorghum is considerably less than that of maize.

*Wheat x a legume species*. Cereal breeders have long dreamed of having a cereal crop such as wheat with typically wheat characteristics aboveground and the root system of a legume such as the pea plant.

Many legumes have evolved a symbiotic relationship (mutually beneficial) with *Rhizobium* bacteria. The bacteria invade the roots of the legume, forming nodules in which they live, grow, and multiply by feeding from the plant supply of sugars and nutrients. *Rhizobia* have the ability to convert nitrogen from the air into ammonia and nitrate which can be used by the plant as a source of nitrogen. By this arrangement, both plants and bacteria thrive even in soils with little or no mineral nitrogen for plant growth.

What a dream to have a wheat crop able to produce its own supply of nitrogenous fertilizer. A wild dream? Perhaps. Until the present it has not been possible to get pollen to germinate in such a wide cross as this. If the new chemical technique could remove this barrier to fertilization, would the seed have a viable embryo? It is not known, but CIMMYT will attempt to find out.

A cereal x legume hybrid could literally revolutionize agriculture, particularly on the impoverished soils that are common in most developing countries. Without dreams such as this, man would cease to progress.

**Summary of potential benefits.** The greatest benefit would be the creation of a whole new range of genetic variability from which the plant breeders can select desirable combinations. Some other benefits: Extention of the range of adaptation to more extreme environments, creation of new types of plant architecture with higher yield potential, transfer of superior disease and pest resistance characteristics into existing crops, new blends of proteins for animal and human food, and new plant genera with unique blends of features—maybe even combining cereals and legumes to revolutionize agricultural production.

It should be appreciated that even if crosses are successful, and viable plants produced between different genera of crop plants, the job of gradually breeding and stabilizing a compatible mixture of chromosomes to produce a superior plant type, will take many years of slow and tedious work. Scientists of many disciplines will need to collaborate to achieve the exciting potential that appears to be opening up.

**The role of CIMMYT and other collaborators.** A wide cross program at this early stage in its development requires cooperative biochemical, cytological, and genetic research coupled with effective embryo culture and breeding capacity and experience. CIMMYT scientists believe that their own research should continue to be production oriented and that the more basic research to support their work should be conducted in collaboration with scientists in universities and national research institutes that are specifically equipped for this work.

Considerable fundamental study is needed to learn more about the biochemical and physiological action of the chemicals used to neutralize cross incompatibility; to elucidate the action of these chemicals on chromosome behavior, to establish more effective ways of treating plants to maximize the effect of the chemicals; to determine cyogenetically what is happening in
the hybrid plants, what is the chromosome number, composition, and behavior; to determine the cytogenetic behavior of the progeny from the initial hybrids; to determine the genetics and chemistry of the protein blends produced; and to elucidate numerous problems as they arise.

Dr. Lynn Bates plans to continue his research on the biochemical aspects of neutralizing the crossability barriers. The research in this area is rudimentary and will need to be expanded if a thorough understanding of the mechanisms involved is to be obtained. Dr. Bates is being supported by The Rockefeller Foundation and the Kansas Agricultural Experiment Station. He will now seek funds to expand his program at Kansas State by including a cytologist and biochemist/physiologist.

Dr. Hayes, Aberystwyth Plant Breeding

*A root tip is removed for cytological studies: counts of chromosomes that reveal whether a wide cross has succeeded or whether the plant is merely the result of accidental self-pollination.*
Station, Wales, is testing the chemicals in actual practice also, and will be able to provide useful data on his experiments in the near future.

Now that details have been published about the original work of Dr. Bates and his CIMMYT collaborators, it is expected that interest and research will be stimulated in many parts of the world.

So far, the CIMMYT staff has tested the various immunosuppressant chemicals suggested by Dr. Bates in actual wide crosses. They have cultured the embryos and treated the resulting viable plants with colchicine to double the chromosome number. Some cytological investigation has been carried out to verify that the resulting plants are in fact hybrids.

There are real advantages in conducting some of the more basic exploratory work at CIMMYT for 2 or 3 years: The ready availability of an extensive range of cereal germ plasm; highly skilled technicians experienced in wide crossing, embryo culture, and colchicine treatment; rapid access to large numbers of resulting embryos that can be transferred directly to greenhouses or laboratory for cytological analysis; and CIMMYT's direct involvement in the exploratory stages will help rapidly to stimulate interest in other institutions and help to link them to funding agencies for financial support if required.

When the validity of the techniques has been adequately tested and research has been stimulated in a few outside research centers, CIMMYT will return to a more applied role. CIMMYT would wish to share in the task of transforming the experimental hybrids into a commercial crop.

A program proposal for CIMMYT. An exploratory wide cross program should be conducted for an initial period of 2 years, followed by a critical review of progress. The research program should be conducted within both the maize and wheat programs in Mexico, being serviced by a common laboratory which will specialize in cytogenetics, embryo culture, and related techniques. So that no long-term commitments are made, the necessary staff for the program would consist of an outstanding visiting scientist to head the laboratory program and two full-time postdoctoral fellows working on wide crosses, one each in the maize and wheat programs. Attempts would be made to have the postdoctoral fellows assigned from leading universities. This method of staff assignment would have the added advantage of bringing experienced research laboratories into the effort.

The total cost of the research program (excluding equipment), would be no more than US$100,000 (including the cost of the cytogeneticist, two postdoctorals, technicians, operating expenses, travel, etc.)

Preliminary discussions have already taken place between CIMMYT and officials of the British Overseas Development Agency (ODA) regarding financial support for the wide cross research program and the necessary equipment. If finally approved, the ODA funds would not be available until 1975, but work could proceed prior to that date as a charge against the grant. The grant, which also would cover other cooperative programs with British scientists, would be for a period of 3 years.

Conclusion. CIMMYT is convinced that an exploratory research program could produce the major expansion in crop germ plasm variability necessary to continue increasing the world's food supplies beyond the end of the century. CIMMYT believes that there is sufficient experimental evidence to proceed to a more thorough investigation of wide crosses, and it is urgent that a start be made if the long and difficult task is to be completed on schedule.
Can barley research be conducted better in the Mediterranean region than in Mexico?

Introduction. In 1973, the Technical Advisory Committee of the Consultative Group for International Agricultural Research asked CIMMYT to comment on a proposal that the responsibility for barley research should be transferred from CIMMYT to a new agricultural research institute in the Mediterranean region. Subsequently CIMMYT submitted a report to TAC stating the opinion of the CIMMYT staff that that wheat and barley research can best be done together on a world-wide basis.

Background. Barley is an important crop on every continent, and in developing countries barley is always grown in the same regions with wheat. The largest national crops of barley are in the temperate zone of Europe and North America, where two thirds of the world’s barley is produced. In 1971 world production of barley was 152 million tons which made barley the fourth-ranking cereal, after wheat, maize, and rice. The Mediterranean region produced 9.5 million tons of barley in 1971, or about 6 percent of the world crop. Barley is used for industrial malting, animal feed, and human food. The three uses of barley each involve distinctive plant types and distinctive grain types. Although only 10 percent of the world’s barley production is for human consumption, barley is nevertheless a major food source for perhaps 200 million persons—most of them with low incomes—because barley grows better than other cereals in dry, cold, high altitude regions of the tropics and in dry, cold areas of the temperate zone. The largest concentrations of barley eaters are, in order of importance, in Eastern and Northern Europe, the Mediterranean and Near East region (Morocco to Afghanistan), India, and the Andean region of South America.

During the last 100 years scientists improved barley greatly, but this work was concentrated on barley for malting and animal feeds in the temperate zone. The greatest gap in barley research relates to human food in the tropics and sub-tropics. Hence a major transfer of scientific skills is now needed from previous research on barley of the temperate zone to food barleys in the warmer climates.

Most barleys used for malting and animal feeds have hulls. When they are eaten as human food, they require milling (pounding) to remove the hull, which also causes loss of nutrients. There are land races (indigenous varieties) of hull-less barley grown in areas like Tibet and the Himalayan foothills of northern India. These land races have desirable kernel type for human food, but they lack protein quality, disease resistance, and other desirable characteristics.

Since all barleys are of the same species, there is no genetic obstacle to creating a new barley type combining high yield, hull-less kernels, and high quality protein for the barley eater. To assemble this new type, some plant characteristics must be obtained from the regions where barley is eaten for food. And some must be obtained from the barleys which have already been improved for malting and animal feeds.

Therefore scientists who undertake to improve food barleys will require broad contacts among cereal breeders in the temperate zone, but they must also use a nursery distribution system which enables them to test experimental barley crops in all the regions where barley is consumed as food.

During the 1960’s and 1970’s the CIMMYT wheat program developed good working relationships with regions where barley is
A barley screening nursery consisting of 381 items was sent for testing in 22 countries of five continents in 1973. The data from this nursery will arrive at CIMMYT in the spring of 1974. CIMMYT will distribute the first nursery of segregating barley lines in 1974.

CIMMYT considers that its breeding efforts for barley will concentrate on the following characteristics during the first 5 years or 10 generations: Wide adaptation, with daylength insensitivity and wide range of maturity; stiff straw to resist lodging; high yield response to nitrogen; semi-lax head to facilitate intake of radiation; spreading root system to support a heavier crop; better resistance to all major insect pests and disease pathogens; good drought tolerance; greater yield stability; and improved protein quality.

The progress of this work in 1972-73 has been greatly speeded by the collaboration of the Mexican government. The Mexican program had previously identified different research stations in Mexico which permit differential screening of the diseases of barley. At these facilities, CIMMYT is able to test for tolerance to each barley disease separately and thus speed up the selection of desirable materials from segregating generations.

The Hiproly gene is greatly speeding work on protein improvement. (The Hiproly gene is a simple recessive gene that greatly increases the percentage of protein and lysine in barley. The Hiproly gene was discovered in the late 1960's by Swedish scientists who were screening the U.S. Department of Agriculture's collection of barley germ plasm for variability in protein.)

All barley crosses are being tested for protein quality by the CIMMYT nutrition laboratory. The CIMMYT protein laboratory is a valuable and integral part of the wheat and barley improvement programs.
As with wheat, CIMMYT's research on barley is proceeding at two generations per calendar year.

Four barley researchers from national programs (Turkey, Syria, Korea) were studying at CIMMYT in 1973.

Advantages of studying both barley and wheat. There are both financial and scientific reasons why wheat and barley should be researched together. Financial reasons are self-evident. CIMMYT uses the same headquarters building, the same experimental land, the same machinery, the same laboratories, the same senior staff for wheat and barley. No capital investment was needed to initiate a barley program "piggy-back" with wheat. One post for a full-time senior staffmember was added in order to manage the barley program. But the entire wheat staff of 13 senior scientists gives part-time assistance. Hence the relatively small budget of $40,000 per year, with which a barley program was started. The $40,000 reflects only supplemental costs. It does not include the part-time use of staff, land, machinery, laboratories, and international consulting. Any other institution wishing to duplicate the barley program of CIMMYT would need to reproduce the entire interdisciplinary staff, plus the capital facilities in land, machinery, and laboratories which CIMMYT uses for wheat.

Other considerations also favor a twin operation on wheat-barley. The two crops generally grow in the same countries. International consulting work on the two crops can therefore be conducted with greater efficiency by the same consultants, visiting the same countries, and dealing with the same officers of national programs. Developing countries generally have a single research unit for wheat and barley.

Breeding techniques on wheat and barley are the same. CIMMYT uses the same technicians (subprofessional staff) for both crops. CIMMYT has already transferred from wheat breeding to barley breeding all that it has learned about the combinations of single crosses, double crosses, top crosses, and back crosses which speed up the concentration of genes for improved characteristics. There is constant exchange of ideas between wheat and barley programs.

Diseases of wheat and barley are similar, although not caused by the same organisms. The pathologists at CIMMYT work on both crops, and there is a transfer of scientific methods, including the search for horizontal resistance to diseases in both crops.

Nursery trials of the crops are managed the same and grown in the same season.

Training of breeders and agronomists from national programs for the wheat and barley crops requires the same skills, and the training staff is the same for both crops at CIMMYT.

CIMMYT resident scientists working in national programs outside Mexico are almost always assigned to help on both wheat and barley.

Finally, radical research on a wheat-barley cross appears likely to become a major activity as soon as triticale (wheat-rye cross) achieves commercial success. There will be advantage for radical research if a complete body of knowledge and trained staffs on wheat and barley crops are available in a single center. This is not a major factor, but one additional advantage in a twin wheat-barley program.

Advantages of global approach. A principal advantage of global research on small grains is the objective of achieving wide adaptability and yield stability. A program which aims for wide adaptability must draw upon germ plasm suited to all agro-climates and all soil types, and must test its progeny in all agro-climates.

It is a central conviction of CIMMYT breeders that yield stability can be achieved
only if the germ plasm combines daylength insensitivity (or almost complete insensitivity), both heat and cold tolerance, tolerance to moisture stress and moisture excess, and resistance to major diseases and insects. Such wide adaptability cannot be achieved if progeny are selected and tested within one climatic zone.

If a research program on wheat-barley must go outside the Mediterranean region to find the diverse conditions for a global research program, then the Mediterranean region offers no special advantages as the headquarters; in fact the region offers less advantages than does Mexico which has widely diverse elevations, moisture conditions, daylengths, and temperatures, all within a few hours travel of each other.

CIMMYT's resources for barley. CIMMYT believes the present resources assigned to barley—a budget of $40,000 per year, including one full-time scientist in charge, plus the part-time assistance of the entire wheat staff, plus use of the CIMMYT capital facilities, plus the advantage of cooperation with the Mexican barley research program which works on malting barley and animal feed barley, plus CIMMYT's established relations with the major national wheat programs and university research programs in North America, Europe, Japan, and Australia—provide optimum support for the second year of an aggressive effort to improve barley as a food cereal.

CIMMYT will require more funds for the barley program as the numbers of segregating generations increase in Mexico, and the numbers of international nurseries and international consultations increase. By the fourth program year (1975) we believe the budget recommendation may rise to $65,000-$70,000. The cost should reach a plateau of about $75,000 (plus inflationary increases) after the fifth year.

For these reasons, the CIMMYT staff believes that global leadership of barley research should remain a twin program with wheat, headquartered in Mexico, and serving all developing countries where barley is grown.

Special report: NEED FOR MORE REGIONAL SERVICES

IN OUTREACH ACTIVITIES

Can national improvement programs for maize and wheat continue to get adequate services from CIMMYT, through its headquarters in Mexico, or is there need to supplement the services from Mexico by additional services located within the regions of the world where maize and wheat are major crops?

Over the next 5 to 7 years, CIMMYT believes there will be need for greater services to national programs from within the regions where maize and wheat are important. By the end of the 1970's there will be
generated by regional testing.

Links between CIMMYT and the regional services for maize and wheat can best be assured by the assignment of CIMMYT personnel to the regions or by training regional personnel at CIMMYT. Clarification is needed on whether regional services can be financed from CIMMYT's core budget.

Regional services. No two regions have the same needs so the services in no two regions need be identical. Nevertheless, there is a general pattern which will apply to most regions, subject to additions here and omissions there. The services include: 1) Distribution of experimental germ plasm for uniform testing by all the grower countries in the region. Some germ plasm will be gathered within the region, some will be exotic. 2) Consultants resident in the region are needed to discuss annual research plans with the national programs. A breeder-agronomist or a plant protection specialist have been found useful in various regions. 3) Training within the region, especially for production agronomists, conducted by a production-agronomist stationed within the region. 4) Regional workshops attended by researchers and production agronomists from the national programs of the region. Outside travel funds are needed to ensure that attendance is not restricted by lack of foreign exchange. 5) A regional newsletter.

What regions? The CIMMYT staff is interested in strengthening the technical services for maize in South and Southeast Asia, tropical East Africa, tropical West Africa, Central America and the Caribbean, the Andean region of South America, and the southern cone of South America, and for wheat in the Mediterranean and Near East region (Morocco to India) and South America.

Regional services have already started. For example, the International Institute of Tropical Agriculture in Nigeria and the Centro Internacional de Agricultura Tropical in Colombia have programs for maize improvement in West Africa and the Andean zone of South America, respectively. The Inter-Asian Corn Program, with headquarters in Thailand, has served countries of South and Southeast Asia. The cooperative maize program among six governments of Central America and Panamá has achieved some results. A cooperative wheat and barley program serving the Mediterranean and Near East region, involving 22 governments, is probably the largest regional network. A cooperative wheat programs for South America started only in 1973.

CIMMYT believes none of these regional services is yet adequate. If each of these efforts is to reach full effectiveness by 1980, a larger consulting staff is needed, possibly 10 to 15 additional persons by 1980; as well as more financial support, possibly $1.5 million a year total by 1980.

Importance of regional links. CIMMYT believes that separation of its headquarters' activities in Mexico from the work of national programs would destroy the conditions for a successful network. CIMMYT has built its past activities upon intimate contact with producer countries. The headquarters staffmembers have traveled extensively, discussing the research in national programs, observing the problems in farmer's fields, and interviewing policymakers.

We now propose regional services not as a substitute for CIMMYT's services to national programs, but as a feasible and economical way to increase those contacts.

Mature scientists from producer countries will continue to spend weeks or months at CIMMYT to observe research methods and give their counsel. Younger scientists from producer countries will continue to spend one crop season in Mexico, sharing in CIMMYT research, and later becoming
Gene Saari, CIMMYT regional pathologist stationed in Lebanon, discusses disease problems with an Afghan scientist in a wheat field near Kabul.

part of the network. These intimate contacts will continue under regional services, if CIMMYT provides the regional staff, and shares in the technical leadership through consultants traveling from Mexico.

Finding new personnel. If CIMMYT proceeds with plans to expand regional services for maize and wheat over the next 5 to 7 years, in regions listed above, this might require 10 to 15 additional regional staffmembers capable of providing the listed services. At the same time, there will undoubtedly be replacement needed for some of the 22 staffmembers now assigned outside Mexico. Moreover, there may be additional national programs requiring bilateral assistance. Thus approximately 20 to 25 scientists might need to be recruited during the next 5 to 7 years.

CIMMYT's best source of new staff-
members is the postdoctoral program which presently has 10 fellows every 2 years, and we are working towards 20 fellows every 2 years.

In a 7-year period, the postdoctoral program could train 50 or more new men, but not all of these men will be available for employment. A 50 percent "slippage" (non-availability) must be allowed because some individuals come from developing countries, hence are expected to serve their own national programs, and because some individuals prefer to engage in some other kind of service after their CIMMYT training.

To end up with 20 new scientists employed in international programs, CIMMYT would need to plan on 50 to 60 postdoctoral fellows in 5 to 7 years.

Special report: FUTURE OF CIMMYT'S ANIMAL NUTRITION LABORATORY

Should CIMMYT continue to operate an animal nutrition laboratory for biologic testing of experimental cereals?

During 1971-73, CIMMYT operated an animal nutrition laboratory using the vole (meadow mouse) as the experimental animal. The animals were fed a balanced diet in which one experimental cereal (wheat, triticale, or maize) was the principal element. The growth rate of the animals was measured by PER (protein efficiency ratio).

PER values determined by these trials at CIMMYT proved unsatisfactory because the variability between individual animals was excessive. The values gave no consistent relationship to the chemical analysis of the same feed materials, nor to results of feeding trials conducted by other research institutions, in which CIMMYT experimental materials were fed to rats, mice, chicks, and swine.

After reviewing the problem CIMMYT decided that selection of protein quality in early generations of cereals can be based upon chemical analysis, without animal feeding trials. But in the future CIMMYT will need two types of research which may involve animal feeding. First, research to identify for the breeders the optimum balance between protein and the limiting amino acids in the protein. Second, testing of protein quality in advanced lines of breeding materials which originate either at CIMMYT or in national programs. The numbers of samples to be tested each year however, do not require an animal laboratory at CIMMYT (50 to 75 experimental varieties of maize per year; 30 to 40 samples of triticale, rising to 50 per year; 15 to 20 samples of barley, rising to 50 per year). A rat-feeding trial for each of these materials would require a 4-kilogram sample for a 28-day test.

CIMMYT has decided that both types of testing should be done in professional animal feeding laboratories elsewhere and CIMMYT has discontinued its animal feeding trials.

In a meeting with two outside consultants, Dr. Alberto Pradilla of the Instituto de Nutrición de Centroamérica y Panamá, Guatemala, and Dr. Armando Shimada of the Instituto Nacional de Investigaciones Pecuarias, Mexico City, four issues were considered: 1) What are the criteria that breeders need to select for nutritional quality in early generations? 2) What techniques should be used for testing advanced lines for nutritional quality? Who will do the testing? 3) What procedures should be used to determine if toxic or antimeta-
bolic factors are significant in the triticale program? When and by whom will the tests be done? 4) Does the environment in which the grain is produced have a significant effect on its nutritional quality?

Selection criteria in early generations. It was reaffirmed that early selection for protein quality and quantity can be based on chemical analyses of the limiting essential amino acids for a specific crop, e.g. lysine and tryptophan for maize, followed by the determination of a full amino acid spectrum for the best selected lines.

For maize, sufficient evidence suggests that 10 to 12 percent protein with 4 percent lysine in the protein will provide reliable selection criteria for well-balanced nutritional quality of the grain. Within this guideline, it is better for the breeder to maintain the lysine content at 4 percent of higher, even at 7 percent protein than to appreciably increase total protein percentage if this means a reduction in lysine.

For triticale, Dr. Zillinsky indicated that no information was available that would provide quality selection criteria. He said, however, that up to 100 triticale lines varying in total protein and amino acid patterns would be available in early 1974. At that time, sufficient seed could be provided for rat feeding trials.

Dr. Shimada offered to carry out the rat-feeding trials at INIP. He needs 20 kilograms of each sample—10 kilograms to be fed in normal diets and 10 kilograms to be prepared as cooked diets.

Nutritional testing of advanced lines. For maize, advanced lines will be tested by
determining PER values with rats. Dr. Shimada agreed to do this work at INIP.
Not all advanced lines need go through this procedure, however.

Dr. Zillinsky indicated that long-term triticale feeding trials were currently being conducted in Obregon by Dr. Rivera, a local research scientist, using swine and chickens. Dr. McGinnis from Washington State University helped design the trials. Advanced lines of triticale will also be tested with rats by Dr. Shimada.

For both maize and triticale, CIMMYT will consider testing of advanced lines in human nutrition trials in the countries where the quality protein lines would be grown.

Two types of testing were discussed: 1) Short-term nitrogen balance and protein efficiency studies with children in a hospital unit lasting 9 to 14 days. 2) Demonstration nutritional tests to illustrate the nutritional value of the new food.

Dr. Pradilla will assist CIMMYT as a short-term consultant if CIMMYT decides to proceed. He suggested the following steps. An experienced nutritionist, should accompany a CIMMYT scientist to the country to survey government interest, available facilities, choice of test village or school, etc. Before starting this type of trial it would be essential to demonstrate that the maize or triticale is significantly superior to the local food. This can be determined by animal feeding trials, e.g. in Ethiopia comparing triticale with teff (a local cereal). For a new source of protein like triticale, trials should be carried out with two monogastric animals first and then humans. This would be satisfied by the rat and swine trials.

Funds would be needed to help organize the human nutrition trials using local workers or helping to train local workers. The trials should be operated locally with local people. The children from the trial village or school should have indications of second or third degree malnutrition. It is important to get large effects, to encourage public adoption of a new food.

Countries worth considering for such a program are Tanzania and Zaire for maize and Ethiopia and India for triticale.

Possible toxic or antinutritional factors in triticale. For triticale, animal nutrition tests should be conducted to an early stage in the breeding program to ensure that no undesirable toxic or antinutritional factors are being introduced.

Selections of triticale harvested from Ciano during the 1968-69 season, when fed to voles by Dr. Elliott of Michigan State University in 1969, provided a wide range of animal growth responses. Some triticale lines were superior to casein as a source of protein, but others were so poor that the voles failed to gain weight or even died. Although vole trials lacked precision, they did identify possible gross differences between the triticale lines tested.

Continuous rigorous selection of only those lines with high PER values, and their reintroduction by crossing into the breeding program has eliminated the suspected toxic or antinutritional factors. But now that CIMMYT scientists are introducing relatively large numbers of primary triticales into the breeding gene pool, possible undesirable factors might be introduced.

When the new lines developed from primary triticales are ready for introduction into the main breeding or crossing block (about 1978) they will be tested with rats. The test diets containing the triticales will be artificially balanced for all essential nutrients, so that the presence of toxins or anti-nutrient factors can be identified by poor growth rates. Subsequent screening may be possible by chemical analysis if any deleterious factors can be identified.

Environment-nutritional quality interac-
tion. No particular effort will be made to study the interaction of environment with nutritional quality because within the range of samples being tested by CIMMYT and other organizations it does not appear to be an important factor.

Special report: POSTDOCTORAL FELLOWSHIPS

How large a postdoctoral fellowship program does CIMMYT need to provide a pool of trained manpower suitable for future employment by CIMMYT and other international centers?

CIMMYT is presently holding back on new outreach projects until it can determine where the personnel will come from. In addition, the possibility of staffing regional service projects could require up to 15 additional CIMMYT staff members within the next 5 to 7 years.

CIMMYT feels that the postdoctoral fellowship program embraces the most suitable age level and is the best type of training to prepare personnel for future outreach assignments.

In 1973 CIMMYT had 14 predoctoral fellows. Half of these were from developing countries (USA, England, Ireland, Sweden, Netherlands, Australia), hence were potential future staff for international centers. The other half were from developing countries (Egypt, Ivory Coast, Thailand, India, Barbados, Chile) and were presumed to be preparing for posts at home.

Even this number may not be adequate. Other international centers made job offers to three of CIMMYT’s regular staff in 1973, and other centers have made inquiries about the availability of nearly all of CIMMYT postdoctoral fellows.

We believe CIMMYT should have a combined intake of about 10 predoctoral and postdoctoral fellows a year to meet the present demand for CIMMYT staff assignment and the inquiries of other centers. About half should be in maize and half in wheat. A few will be in economics. Some of these will return to their home countries at the end of their grants. Some will decide against a career in international agriculture. If half of all fellows are found suitable to join the staff of CIMMYT or other centers, this would be a successful outcome.

To sponsor a program of this magnitude CIMMYT requires more apartments at its headquarters, and more vehicles to assign to fellowship families.
1973 CIMMYT sources and application of funds

The following data are from the 1973 CIMMYT Audit Report of Price Waterhouse y CIA., S.C., Mexico.

<table>
<thead>
<tr>
<th>$ (US$)</th>
<th>Source/Description</th>
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| 2,533,000 | Core unrestricted income $a$
| 1,500,000 | U. S. Agency for International Development
| 1,334,000 | International Bank for Reconstruction and Development
| 750,000 | Ford Foundation
| 750,000 | The Rockefeller Foundation
| 461,000 | Government of West Germany
| 461,000 | Administrative charges and miscellaneous income
| 964,000 | Core restricted income $b$
| 493,000 | United Nations Development Programme
| 331,000 | Canadian International Development Agency
| 118,000 | The Rockefeller Foundation
| 12,000 | International Development Research Centre (Canada)
| 1,605,000 | Special projects income $b$
| 997,000 | Ford Foundation
| 248,000 | U. S. Agency for International Development
| 219,000 | Government of Zaire
| 154,000 | Programme National Maïs, Zaire
| 56,000 | International Development Research Centre (Canada)
| 55,000 | Inter-American Development Bank
| 14,000 | Purdue University
| 7,000 | International Institute of Tropical Agriculture
| 55,000 | Training grants from seven donors
| 8,012,000 | TOTAL INCOME
| 5,146,000 | Unrestricted expenses
| 1,008,000 | Wheat
| 712,000 | Maïs
| 170,000 | Puebla Project
| 139,000 | Economics
| 436,000 | Experiment stations
| 74,000 | General service laboratories
| 279,000 | Information services and library
| 410,000 | General operations
| 610,000 | Administration
| 1,290,000 | Capital acquisitions
| 1,178,000 | Restricted expenses
| 1,014,000 | Direct expenses
| 164,000 | Administrative charges
| 1,358,000 | Special projects expenses
| 1,170,000 | Direct expenses
| 188,000 | Administrative charges
| 7,682,000 | TOTAL EXPENSES
| 330,000 | Reimbursements to donors and unexpected balances
| 330,000 | For restricted and special grants and working capital
| 8,012,000 | TOTAL EXPENSES, REIMBURSEMENTS, AND BALANCES

$a/$ Funds available for core operations without restriction for use within the budget approved by CIMMYT Trustees.

$b/$ Funds available only for the activity specified by the donor.