



# CIMMYT

**Research Highlights 1984**

International Maize and Wheat Improvement Center

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The International Maize and Wheat Improvement Center (CIMMYT) is an internationally funded, nonprofit scientific research and training organization. Headquartered in Mexico, CIMMYT is engaged in a worldwide research program for maize, wheat and triticale, with emphasis on food production in developing countries. CIMMYT is one of 13 nonprofit international agricultural research and training centers supported by the Consultative Group for International Agricultural Research (CGIAR). The CGIAR is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). The CGIAR consists of 40 donor countries, international and regional organizations, and private foundations.

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## Introduction

Maize and wheat are the principal sources of carbohydrates and protein for nearly half of the people of the world. CIMMYT's primary objective is to develop superior germplasm that will provide higher and more stable yields, as well as better nutritional quality. Toward this objective, CIMMYT conducts and helps to implement research, training and information programs designed to improve maize and wheat production in the developing countries of the world. The Center currently conducts research on maize, bread wheat, durum wheat and triticale.

In the development of its research products—primarily improved germplasm and more effective procedures for conducting crop improvement and production research—CIMMYT seeks to serve as broad a clientele as possible. This is reflected in the emphasis placed on developing broadly adapted germplasm to serve as genetic stock for use by scientists in more than 125 countries. National programs, in turn, use CIMMYT materials as germplasm sources to develop and release varieties and hybrids which are more adapted to local conditions.

Despite the tremendous food production successes achieved in recent decades in Asia and parts of the Middle East and Latin America, developing country governments face even greater production challenges during the balance of this century to feed future generations. First, the more-favored environments cannot be neglected, since substantial yield improvements are still achievable and necessary. However, the major unexploited production gains must be made through the application of new technologies—which are economically viable and sustainable—to the more marginal cereal production environments of the developing world.

Some 600 million people live in the semi-arid tropics and more than 1 billion live in tropical and subtropical areas. These two regions are characterized by serious biological constraints in terms of moisture and temperature stresses, soil fertility and toxicity problems, and diseases and pests. The number of people inhabiting these less-favored areas is expanding at an alarming rate. Africa, in particular, is in a critical situation having experienced declining per capita food production for more than a decade and serious deterioration of agricultural lands.

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Although some of the biological limitations are simply too overpowering to erase with current techniques, newly applied science and technology can ameliorate many of the important constraints found in these marginal lands.

CIMMYT's research agenda for the 1980s places major emphasis on the generation of new technological components that can increase yield dependability in less-favored rainfed environments. Two major research approaches are being pursued in CIMMYT's germplasm development work. One involves applying conventional breeding procedures in search of genetic variation within a particular crop species for added tolerance or resistance to specific environmental stress conditions. Improved genetic materials—in terms of drought, cold and heat resistance, and tolerance to mineral stresses such as those found in saline and acidic soils—are emerging from this work. Research directed at crossing domesticated crop species with other related crops and wild species is another promising avenue that is likely to lead to the development of varieties with greater yield potential and dependability in a number of important marginal areas.

CIMMYT's initial work with wide crosses was with triticale, a hybrid cross of wheat and rye. Our work today is less concerned with creating new crop species than with transferring useful genes from related species to wheat and maize.

Fortunately, the agricultural production potential in the Third World is large and still considerably under-exploited. To capitalize on this potential, agricultural development programs must be built on firmer foundations of: (1) research systems capable of generating improved technologies appropriate to the production circumstances of farmers; (2) more-effective investments in the rural sector in land and water resource development, input production and distribution systems (including credit), and transportation and grain storage facilities; and (3) policies which stimulate increased agricultural productivity in ways consistent with the wise use of endowed resources.

In too many countries, relatively low priority is still given to agricultural sector investments and farmers continue to be constrained by government food policies designed to placate the more vocal and organized urban groups. Too often, these domestic "cheap food" policies have been reinforced by easy-term food aid and/or surplus disposal programs sponsored by food-surplus nations.

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Such policies have, time and again, retarded agricultural development in food-deficit developing nations. Obviously, humanitarian food-aid in times of emergencies caused by wars and natural disasters, such as droughts, floods, and disease epidemics, is a necessity, but not a long-run solution. One hopeful sign in the 1980s, however, is the number of developing countries that are changing their policies to remove the bias against agriculture.

The development and widespread application of adapted and more productive technologies is required to transform those farming systems in the developing world which have yet to benefit greatly from agricultural research. Aggressive, production-oriented interdisciplinary research efforts, in which on-farm research forms an essential component, will be an especially important factor in achieving this goal.

Effective research programs will also require greater continuity of scientific personnel and program objectives. It generally takes a minimum of eight to ten years of creative, dedicated and adequately supported research work in various disciplines to produce the information and materials (varieties) from which improved production practices can be formulated.

Despite the dramatic improvement made in food supplies in the past 30 years, the challenges for CIMMYT and other national and

international agricultural research organizations remain enormous. Although slowing, world population growth is an underlying force driving demand for grain upwards at a rate that remains particularly high in developing countries. Income growth and associated changes of lifestyle and urbanization are also likely to boost the demand for crops within CIMMYT's mandate. These factors mean that in the space of the next 40 years, the world will have to grow two to three times more grain each year than is grown at present. Couple this with the need to increase food availability to millions of malnourished people and the size of the task ahead for CIMMYT and other agricultural organizations takes the proper perspective.

In the pages which follow, highlights of the CIMMYT research program of work are provided. These activities are "snap shot" profiles of selected research thrusts, each of which is at a different stage of development and impact. We believe that the activities described herein reflect a growing research capacity—within CIMMYT and in national research programs—for improving cereal yield levels on millions of less-productive lands found throughout the developing world.



R.D. Havener  
Director General



### Introduction

Though the 1970s saw improvement in developing country maize production, brought about in part by yield increases of 2.6% per annum, low yields remain one of the facts of life for many maize farmers throughout the Third World. Working in extremely harsh environments, these farmers have had few options for protecting their crops against insect pests, diseases, and the vagaries of tropical weather. In much of the lowland tropics they are often fortunate to harvest 1 t/ha and generally lose a portion of that during storage and transport.

For centuries yields that seem abysmally low by present standards have at least been sufficient to provide farm families a living. But now rampant population growth in developing countries, accompanied in many regions by extremely high pressure on the land, are upsetting the delicate equilibrium of subsistence agriculture. Farmers increasingly have to produce more food to meet not only their own needs but those of growing urban populations.

Many changes in agricultural technology and in the conditions that affect its availability and usefulness to farmers will be required to lift developing country maize yields. Among the most urgent requirements is to harness the rich genetic resources in maize

through germplasm development and to deploy this improved material more vigorously than has been done to date in developing countries. As long as fertilizers, pesticides, and other means of improving crop production remain beyond the reach of the average Third World farmer, improved varieties, along with low-cost and appropriate cultural practices, will be the most efficient and, in some cases, practically the only way of providing immediate help to maize growers in their efforts to satisfy the new demands being placed on them.

### Multistage Germplasm Development and Distribution

In the mid-1970s CIMMYT scientists instituted a system for population improvement and international testing that is proving to be quite responsive to farmers' changing needs and extremely flexible in the development of germplasm for the wide-ranging growing conditions in some 80 countries around the world. As of 1984, 800 experimental varieties and hybrids have been developed through this system, and of those we have reports that approximately 150 superior ones have been released to farmers by 39 national programs.

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These improved varieties are the end-product of a multistage process that begins with recombination and improvement, under fairly mild selection, of CIMMYT's 33 normal maize and 17 quality protein maize (QPM) gene pools, large reservoirs of genetic variability that are classified according to zone of adaptation, maturity period, and grain type and color.

From the most promising fractions of these pools, CIMMYT scientists have derived 23 normal and 10 QPM advanced populations that are superior in yield and other attributes. In a continuous cyclical process, these populations are undergoing further improvement with a higher selection intensity and are being made available to cooperators in national programs through International Progeny Testing Trials (IPTTs).

In each IPTT the full-sib progenies of a particular population are tested at up to six locations around the world. The results of those trials are used for two purposes. First, based upon information provided by the trial cooperators, CIMMYT scientists select the best 50-60 families for within-family improvement, recombination, and regeneration of each population for the next cycle of improvement.

The second and more important use of IPTT results is for the development of experimental varieties (EVs), some of which are derived from the 10 best families at

each location and others from the 10 best families across locations. These varieties are advanced to the F<sub>2</sub> stage and dispatched to cooperators in the form of Experimental Variety Trials (EVTs), each of which is evaluated at 30-50 locations. After the data from these trials have been analyzed, CIMMYT scientists select the top-performing varieties to prepare Elite Variety Trials (ELVTs), which are distributed to 60-80 locations and conducted in much the same way as the EVT's. Results for all three types of trials are distributed to cooperators, who can then decide whether to use superior germplasm as introductions in breeding nurseries or as potential varieties that could be tested in farmers' fields and eventually released. CIMMYT supplies small quantities (up to 3 kg) of seed of selected materials to national programs at their request.

### **Strengthening National Research Programs**

CIMMYT's involvement with national programs extends considerably beyond coordination of the international trials. Nearly half of the Center's maize scientists are posted around the world in six regional programs (and some bilateral national programs) that were set up to help national researchers take full advantage of improved germplasm. The assistance provided by CIMMYT's regional staff takes several forms; among the principal duties of these scientists are to monitor



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international nurseries, help develop strong national maize research programs in which station-based and on-farm trials are integrated, study socioeconomic constraints of maize production, and help national programs to tackle various agronomic and pest problems. In the course of this work, CIMMYT scientists also identify promising candidates for various types of training. By 1984 some 800 persons had received in-service maize training at the Center, representing a substantial enrichment of national research capabilities.

### **This Year's Highlights**

The combination of CIMMYT's population improvement scheme and international testing and regional programs encompasses many diverse lines of research on numerous problems with which farmers in the Third World are faced. This report highlights both the methods and progress of several of these research activities, which are listed below:

- Approaches for developing resistance to maize streak virus in Africa
- A method of breeding for improved husk cover in tropical maize
- Successes in overcoming the early drawbacks of high lysine maize and increasing the use of QPM in national programs
- A systematic test of CIMMYT's population improvement scheme

- Improvements in the Center's facilities and procedures for handling maize germplasm bank materials

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### **Streak-Resistant Varieties for Africa**

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Since 1980 CIMMYT has been engaged in a joint effort with the International Institute of Tropical Agriculture (IITA) in Nigeria to combat maize streak virus (MSV) disease, which is among the most serious disease problems of maize in sub-Saharan Africa.

The magnitude of yield losses varies from season to season and depends on the percentage of plants infected and the growth stage at the time of infection. Severe outbreaks often occur in late plantings or in second-season maize. Under artificial epiphytotics at IITA, streak has caused yield losses of up to 100% in experimental plots. During 1983 and 1984, MSV epidemics devastated maize production in several countries of West Africa, where crops were already suffering from the effects of uneven rainfall distribution.

The virus is transmitted by leafhoppers of the genus *Cicadulina*. The epidemiology of the disease is closely tied to the population size of this vector, which is in turn influenced by rainfall, temperature, and the availability of alternate hosts.

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Variations in these conditions explain the erratic occurrence of the disease over seasons and years.

Yield losses can be controlled to some extent through agronomic practices such as timely planting and treatment of seed with systemic insecticides. But a more effective and practical solution to the problem, and the one being sought by the CIMMYT/IITA African Maize Program based in Nigeria, is to introduce MSV tolerant, high yielding, adapted varieties into national programs for widespread distribution among African farmers.

Excellent progress has already been made in putting this solution into effect. A reliable screening technique has been developed, sources of streak resistance identified, and resistant varieties placed in the hands of national maize researchers.

### **Screening Techniques**

Developing a reliable means of screening for MSV resistance was an important early step in bringing plant breeding techniques to bear upon the disease problem. Since the natural occurrence of MSV is so erratic, significant genetic gains would have been extremely difficult to make through routine field selection.



MSV resistant conversions of CIMMYT elite varieties developed at IITA in Nigeria should provide farmers in sub-Saharan Africa with good protection against this devastating disease.

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Reliable, large-scale screening became possible when scientists at IITA developed methods for mass rearing of MSV's leafhopper vector. Gradual improvements in these methods have boosted weekly rearing capacity to 200,000 *Cicadulina* adults, which are fed on infected maize plants and can then be released in the field for resistance screening on as many as 50,000 plants per week.

Researchers are monitoring the uniformity of infestation by planting susceptible check rows at regular intervals and are finding that the infestation is quite uniform and the chance of "escapes" minimal.

### **Sources of Resistance**

In 1975 streak resistance was found in the maize population TZ-Y, which was based at least partly on yellow segregants from the CIMMYT population Tuxpeño Planta Baja. A number of lines were developed from TZ-Y through continuous selfing under artificial streak infection. One of these, IB32, has been widely used at IITA as a donor for streak resistance. Resistance was also discovered in 1976 in the variety La Revolution from Reunion Island and in a Tuxpeño X Ilonga composite from Tanzania.

In 1977 white grain and yellow grain populations—TZSR(W) and TZSR(Y)—were developed from TZ-Y at IITA. These populations showed good streak resistance but had a rather narrow genetic base and other drawbacks, including poor standability.

Over the next several years, IITA scientists made several observations that had important implications for work on streak resistance. They learned that in IB32 no more than three major genes are involved in controlling streak resistance, that modifier genes also influence disease expression, and that the streak resistance in La Revolution is monogenic.

### **Developing Adapted Germplasm**

Because of the rather simple inheritance of streak resistance and the effective screening techniques devised at IITA, researchers have made rapid progress in developing adapted, streak resistant germplasm for African national programs. The methods and progress of various approaches that have been taken are discussed in the following sections.

**Broadening the genetic base of TZSR(W) and TZSR (Y)**—These populations, developed in 1977 at IITA from TZ-Y, have shown good streak resistance, but have a rather narrow genetic base and agronomic problems such as poor standability. To correct these deficiencies, two other IITA populations and experimental varieties developed in 1974 from CIMMYT's populations 21 and 22 have been introgressed into TZSR(W), and TZSR(Y) has been crossed with Poza Rica 7428, with a Nigerian variety, and with IB32 X La Revolution (a cross between two sources of streak resistance).

In both populations half-sib families were formed under streak pressure during the dry season of 1979-80. These were tested during the following growing season at five locations in Nigeria and one in Burkina Faso (formerly Upper Volta). The best 50 families in each population were recombined to form TZSR-W-1 and TZSR-Y-1. Then, in 1981 full-sib recurrent selection was begun (according to much the same scheme as that used at CIMMYT) in cooperation with national programs in Africa.

Two early maturing, streak resistant populations—TZESR-W and TZESR-Y—were developed in 1977 by crossing early maturing materials with TZSR(W) and TZSR(Y). During subsequent seasons these crosses were advanced to S<sub>3</sub> lines under streak pressure. Selected lines were then

recombined to form the two early maturing populations, and families of these populations were tested for yield in Nigeria during 1981. In the following year, recurrent full-sib selection for yield and other agronomic characters was begun in cooperation with national programs, and the level of streak resistance in selected families was monitored at IITA.

More recently, work has begun on the incorporation of streak resistance into CIMMYT's pool 16, which is an early white dent material and has performed well in the semiarid regions of Africa. In addition, three new populations have been developed: TZMSR-W for midaltitude regions, and TZUT-W and TZUT-Y, which are based on crosses between U.S. and tropical maize.

**Table 1. Grain Yield in IPTT 43 (La Posta), 1982**

	Honduras (Catacamas)	Ivory Coast (Ferke)	Nicaragua (St. Rosa)	Nigeria (Ikenne)	Thailand (Suwan)	Zimbabwe (Gwebe)	Mean (6 Locations)
Selected families	7.87	9.64	6.25	7.09	8.56	9.15	7.45
Population	6.63	7.83	4.89	5.12	6.62	6.67	6.29
Best check	5.51	9.31	5.40	5.44	7.25	12.35	7.54
C.V.	13.7	11.7	17.3	16.6	11.8	13.1	

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**Recurrent selection in La Posta (population 43)**—This population, which consists of late white dent material derived from CIMMYT’s Tuxpeño gene pool, has performed well in the lowland tropics of Latin America, West Africa, and parts of East Africa, as indicated in Table 1, which reports results of International Progeny Testing Trial (IPTT) 43 in 1982. Various selections from La Posta have been released by national programs to farmers and are widely grown in several African countries.

Because of the high demand for this material in Africa, it was decided to transfer the center of population improvement for La

Posta from Mexico to IITA, where efforts were begun to develop streak resistance in the population through a procedure illustrated in Figure 1 and described below. At the same time, however, recurrent selection for yield and other agronomic characters was continued, so that researchers could keep upgrading the population and developing experimental varieties from it.

During the same season in which IPTT 43 was conducted (year 1, season A), the 250 full-sibs tested were screened for streak resistance at IITA, and plants showing resistance were selfed. In the first cycles of screening, only a few

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<b>Year 1</b> A Season	IPTT 43 with 250 families in 6 countries. Streak screening of 250 families, resistant plants selfed. 250 families planted under streak protection, good plants selfed.
<b>Year 1</b> B Season	Streak screening of S <sub>1</sub> progenies from families selected based on IPTT data. Selfing or sibbing within each selected progeny. Nonresistant progenies from selected families selfed in protected nursery.
<b>Year 2</b> A Season	Two plantings of selected progenies: under streak and protected. Recombination of selected progenies by bulk sibbing among selected lines. Where possible, streak resistant lines represent original full-sib they were derived from.
<b>Year 2</b> B Season	Two plantings of selected progenies: under streak and protected. Generation of 250 full-sibs by plant-to-plant crosses. Where possible, streak resistant progenies represent original full-sibs they were derived from.

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**Figure 1. Simultaneous improvement of agronomic characters and streak resistance within La Posta**

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families had plants with streak resistance; all the rest were completely wiped out by the disease. So, all 250 families were planted in a different nursery protected with Furadan, plants were selected for good plant type, and those selected were selfed. The S<sub>1</sub> progenies of the plants selected in the streak nursery represent the original full-sib families from which those progenies were derived.

Normally the results of the IPTTs are not received early enough to be taken into account in the selection of families before the next growing season. For that reason S<sub>1</sub> progenies from most of the 250 original full-sib families were planted in year 1, season B, and the progenies were selfed or sibbed. Three S<sub>1</sub> progenies from each original full-sib were planted and the best one or two selected.

Once the results of the IPTTs were received, about 30% of the best families in La Posta were selected (in year 2, season A) on the basis of the trial results. The S<sub>2</sub> progenies saved from the streak nursery were planted under streak pressure and the nonresistant ones under streak protection. Selected lines were recombined by bulk sibbing, with each of the original full-sib families contributing equally.

In year 2, season B, the half-sib families were planted in two separate nurseries, one under streak pressure and the other with streak protection. Full-sibs were then made through reciprocal plant-to-plant crosses. In doing so researchers attempted to obtain an equal contribution from each of the originally selected full-sibs and to use as many plants as possible from the streak nursery.

This approach to developing adapted streak resistant germplasm proved to be extremely effective. Whereas in 1980 only 4.6% of the selected families had plants showing resistance, in 1984, after three cycles of selection, the figure was up to 100%; in every family screened at IITA, some plants with streak resistance were found. The best plants from each family were selfed, and the S<sub>1</sub> lines will be screened and advanced to the S<sub>2</sub>, at which point they will be recombined for the next cycle of selection. Researchers expect that the population will have a high level of streak resistance by 1986 and that all varieties derived in the future from La Posta will be streak resistant.

**Conversion of experimental varieties**—The third approach in breeding for streak resistance has been to convert elite varieties by backcrossing. For the past ten years, most national programs in Africa have been receiving such

varieties through CIMMYT's International Maize Testing Program and either using them in their own breeding work or releasing them to farmers. Now these varieties are being converted to streak resistance, so that African national programs can quickly obtain and put to use this means of protection against MSV for the whole range of maize growing environments.

Taking advantage of CIMMYT's ongoing population improvement efforts, breeders are using the most recent experimental variety from populations that have performed well as a recurrent parent in each backcross generation. About 4,000 plants are screened for streak resistance in each generation, 100

or so are selected, and the progenies of selected plants are grown ear-to-row during the following season. Enough plants of the recurrent parent are sampled to recover fully the gene frequencies that are characteristic of the variety undergoing improvement.

This approach has given very encouraging results. In a study conducted in Nigeria comparing the streak resistant conversions with the recurrent parents under artificial streak infection, the conversions were decidedly superior in yield and other agronomic characters under very heavy streak pressure (Table 2). Nor has streak resistance been gained at the expense of yield potential, according to the results

**Table 2. Comparison of streak resistant conversions and non-streak resistant counterparts in EVT-LSR(W) and (Y) under streak at Ibadan, Nigeria, 1983**

Trial	Variety	Grain yield (kg/ha)	Days to silk	Plant ht. (cm)	Ear ht. (cm)	Streak (1-5)
EVT-LSR(W)	Poza Rica 7722	901	63	132	74	5.0
	P.R. 7722-SR BC <sub>2</sub>	7040	56	215	113	2.3
EVT-LSR(W)	Across 7729	1087	62	140	72	5.0
	Across 7729-SR BC <sub>2</sub>	7050	54	212	107	2.3
EVT-LSR(W)	Poza Rica 7843	1502	60	165	80	5.0
	P.R. 7943-SR BC <sub>2</sub>	7400	55	242	128	2.5
EVT-LSR(Y)	Across 7728	857	61	113	76	4.8
	Across 7728-SR BC <sub>2</sub>	6743	55	234	133	2.3
EVT-LSR(Y)	Tocumen (1) 7835	1435	58	120	54	3.5
EVT-LSR(Y)	Tocumen (1) 7835-SR BC <sub>2</sub>	5118	50	206	103	1.3

of another experiment. Under no streak pressure, the resistant varieties yielded just as well as their normal counterparts, as indicated by the data in Table 3.

The first varieties from the conversion program are now being multiplied and have been released to farmers in Benin and Togo and in several other countries are being tested in national variety trials and on-farm trials. Two additional steps will make resistant germplasm more widely available to African farmers. The first has been to organize trials in 1984 that include the streak conversions and varieties derived from IITA populations, and to distribute these trials among cooperating maize researchers throughout sub-Saharan Africa. These researchers will make further selections and then either distribute the resistant varieties directly to farmers or integrate them into the national breeding program.

The second step will be to introgress streak resistance into each population from which the conversions were derived and to build this resistance up to high levels through screening under artificial streak infection in Nigeria or elsewhere in Africa. Introgression of streak resistant conversions into the gene pools corresponding to the populations has already been started at CIMMYT, and within a few years, all the populations that are important for Africa should have strong resistance to MSV.

### Breeding for Improved Husk Cover in Tropical Maize

However successful they might be in adding disease resistance or making other useful modifications in maize, plant breeders are still hard pressed to develop improved germplasm that is preferable in every way to local varieties.

**Table 3. Comparison of streak resistant conversions and non-streak resistant counterparts tested at Ikenne, Samaru, and Gusau, Nigeria, 1983. Streak incidence negligible**

Variety	Grain yield (kg/ha)	Yield index*	Days to silk	Plant ht. (cm**)	Ear ht. (cm**)
Across 7728	5743	100	57	219	114
Across 7728-SR BC <sub>2</sub>	6391	111	57	231	129
Tocumen (1) 7835	5088	100	51	206	100
Tocumen (1) 7935-SR BC <sub>2</sub>	5497	108	51	197	96

\* Non-streak resistant variety = 100

\*\* Data from Samaru and Gusau only



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Farmers have their reasons for remaining loyal to these varieties, such as appropriate cooking quality, grain type, and color, and improved materials that lack such characteristics may stand a poor chance of being widely adopted.

One of the present deficiencies of some high yielding, broadly adapted maize populations with improved plant type is their relatively poor husk cover. In this respect they are inferior to the best local varieties grown by farmers in the humid tropics, which generally have good husk cover but cannot compete with the improved materials in yield potential.

Husk cover is extremely important in maize and can have a direct effect on the farmer's yield. Throughout the humid tropics, maize is often left to dry in the field from one to six months, or the unhusked ears are stored without insecticide treatment. Without good husk cover, farmers would suffer far higher grain losses than they already do from bird damage, ear rots, and especially insect damage. Although other factors, such as antibiotics, are also important in reducing grain losses to insect pests in the field and in storage, good husk cover is the farmer's first line of defense against disastrous losses.

This defense mechanism is so important that breeders in national programs often carry out several cycles of selection under local conditions to improve the husk cover of high-yielding materials so as to make them acceptable to farmers. In an effort to help eliminate this extra step in tailoring maize to fit local conditions, a CIMMYT scientist conducted research at several locations in 1984 on S<sub>1</sub> progeny selection for breeding high yielding, nitrogen responsive maize varieties that also possess good husk cover. The results indicate that this method is quite effective for improving husk cover and only slightly less so for boosting yield potential. Application of this technique should be extremely helpful to national researchers in streamlining the delivery of improved varieties to farmers.

### **Research Methods**

The genetic materials chosen for this study were pool 20 (a tropical intermediate white dent) and population 21 (Tuxpeño 1, a tropical late white dent), both of which are well adapted to humid tropical regions from 0 to 1600 m above sea level. About 1500 S<sub>0</sub> plants of each material were selected at anthesis and self-pollinated during the winter season of 1984 at CIMMYT's lowland experiment station in Poza Rica, Mexico. The criteria for selection were plant type, resistance to foliar

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diseases (especially *Helminthosporium turcicum*), and synchronization between silking and pollen shedding. At harvest large, disease-free, well-filled ears of the proper grain type and texture were selected from plants showing resistance to lodging and stem rot. A total of 368 S<sub>1</sub> progenies of each material were chosen for testing.

During the summer season of 1984, these progenies were tested at a low plant density of 30,000 per hectare; 200 kg N/ha was applied to allow maximum expression of differences between families in husk cover traits. The experiment had a replications-in-blocks (nested) design, with two replications at each test location. S<sub>1</sub> families of pool 20 were grown at the CIMMYT experiment stations in Poza Rica and Tlaltizapan, Mexico, and at Villa Cardel near Veracruz, Mexico, in cooperation with Antonio Narro University. S<sub>1</sub> families of population 21 were tested at the same two CIMMYT stations and at San Jeronimo, Guatemala, in cooperation with the Instituto de Ciencia y Tecnología Agrícolas.

Immediately before harvest, data were taken on poor husk cover and husk extension of dry ears. If any portion of an ear was not completely enclosed by the husks,

it was classified as having poor husk cover. For each plot the number of ears with poor husk cover was divided by the total number of ears to arrive at percent poor husk cover. Husk extension of ears with good husk cover was



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determined by measuring the distance from the tip of the ear to the tip of the husk. For ears with poor husk cover, the distance from the basal exposed portion of the ear to the ear tip was measured and recorded as a negative value.

Husk tightness was also rated just before harvest in each plot on a scale of 1-5, in which 1 is extremely tight and 5 extremely loose. Ears from each plot were rated for insect damage on a scale of 1-5, where 1 indicates no damage and 5 all ears damaged. Estimates of variance components and heritability were calculated using data from the combined analysis of variance.

### Research Results

In both pool 20 and population 21, the ranges between minimum and maximum S<sub>1</sub> family means for each trait were several times the LSD value, as shown in Table 4. Such highly significant differences indicate that it is quite possible to select effectively for all the traits. Differences among families were especially large for percent husk cover, husk extension, and grain yield. Fourteen percent of the S<sub>1</sub> families in pool 20 had perfect husk cover and 13% in population 21. The worst family in pool 20 averaged 69% poor husk cover and in population 21, 78%. In the gene pool, husk extension ranged from -2.48 to 11.50 cm and in the

population from -1.68 to 11.27 cm. There was a wide range among families in pool 20 for grain yield, as a result of its extremely broad genetic base. Population 21, though it is at a more advanced stage of improvement and has a narrower genetic base than the pool, also showed quite a wide range in grain yield.

The heritability estimates given in Table 4 indicate the degree to which the superiority of the selected families can be expected to be passed on to the next generation. The values in the column headed "progeny basis" are estimates of heritability for selections based on the combined analysis of data from three locations, with two replications at each site. The "plot basis" figures indicate heritability for selections based on data from an unreplicated planting at only one location. Since genotype-environment interactions were highly significant for every trait, the plot basis estimates of heritability were much lower than the progeny basis estimates. Obviously, multilocational replicated trials are essential for rapid improvement of the traits considered in this study.

Good husk cover in improved maize: the farmer's first line of defense against disastrous losses to pests.

Progeny basis estimates of heritability were greatest for husk extension and percent poor husk cover, principally because testing of the S<sub>1</sub> progenies at low plant density, under high fertility, and in several different environments allowed excellent expression of genetic variability for these traits. Heritability estimates were intermediate for grain yield and lowest for damage by ear insects and husk tightness. The low estimate for insect damage may have been the result of low natural infestation. Conditions for the expression of husk tightness,

however, should have been optimal. The low heritability estimate for this trait suggests that effective selection would be difficult with the rating method used in this experiment.

Most of the phenotypic correlations between traits were quite low, as shown in Table 5, except for that between percent poor husk cover and husk extension (-0.65 for pool 20 and -0.61 for population 21), and that between grain yield and damage by ear insects (-0.49) for the pool. Though some families with good husk cover had short

**Table 4. Overall means, S<sub>1</sub> family means, and estimates of heritability from a husk cover study**

Trait	Genetic material	Overall mean	S <sub>1</sub> family means			Broad-sense heritabilities	
			Minimum	Maximum	LSD (.05)	Progeny basis	Plot basis
Grain yield (t/ha)	Pool 20	3.03	1.27	6.96	0.92	0.76	0.39
	Pop. 21	3.23	1.64	5.11	1.02	0.58	0.23
Poor husk cover ( <sup>o</sup> /o)	Pool 20	10.35	0.00	69.20	12.73	0.85	0.51
	Pop. 21	10.50	0.00	77.84	13.81	0.82	0.46
Husk tightness rating <sup>a/</sup>	Pool 20	2.92	1.67	4.17	0.97	0.30	0.08
	Pop. 21	2.54	1.17	3.83	0.97	0.44	0.13
Ear insect damage rating <sup>b/</sup>	Pool 20	2.20	1.00	3.33	0.67	0.44	0.13
	Pop. 21	2.10	1.17	3.67	0.83	0.44	0.12
Husk extension (cm)	Pool 20	5.14	-2.48	11.50	1.85	0.91	0.66
	Pop. 21	4.89	-1.68	11.27	1.77	0.91	0.67

Note: Comparison of data from pool 20 with that from population 21 is not warranted since the two were planted in separate experiments, at different dates, and at a different third location.

<sup>a/</sup> Rated on a scale of 1-5, in which 1 = extremely tight and 5 = extremely loose.

<sup>b/</sup> Rated on a scale of 1-5, in which 1 = no damage and 5 = all ears damaged.

husk extensions, most of the ones with perfect husk cover had husk extensions of at least 5 cm. The high correlation between yield and ear insect damage in pool 20 was related to its high susceptibility to ear rots, which are considerably worsened by ear insect damage. For this reason, families that were very susceptible to ear insect feeding yielded poorly.

All of the other correlations were so low as to have little practical significance. Of particular importance was the very low correlation between grain yield and percent poor husk cover (0.04 for the pool and 0.02 for the population), which indicates that one can select S<sub>1</sub> families that have both high yield potential and

good husk cover. S<sub>1</sub> progeny selection is less effective, though, for improving ear insect resistance (without artificial infestation) and husk tightness.

It also appears from the results of this experiment that measuring husk extension, a very time-consuming and laborious process, is unnecessary in selecting for good husk cover. Determining percent poor husk cover, which was only slightly less heritable than husk extension, is a far simpler and quicker means of accomplishing the same end. This method is particularly suitable for maize improvement programs that do not have computers, since it requires far fewer calculations than measuring husk extension.

**Table 5. Phenotypic correlations in a husk cover study (N = 2208)**

Trait	Genetic material	o/o poor		Ear	
		husk cover	Husk tightness <sup>a/</sup>	insect damage <sup>b/</sup>	Husk extension
Grain yield	Pool 20	0.04*	-0.02 <sup>ns</sup>	-0.49**	-0.23**
	Pop. 21	0.02 <sup>ns</sup>	-0.10**	-0.24**	-0.31**
o/o poor husk cover	Pool 20		0.10**	0.05*	-0.65**
	Pop. 21		-0.05*	0.13**	-0.61**
Husk tightness	Pool 20			-0.00 <sup>ns</sup>	-0.00 <sup>ns</sup>
	Pop. 21			-0.01 <sup>ns</sup>	0.13**
Ear insect damage rating	Pool 20				0.07**
	Pop. 21				0.03 <sup>ns</sup>

\* Indicates statistical significance at the 0.05 level.

\*\* Indicates statistical significance at the 0.01 level.

<sup>ns</sup> Not statistically significant.

<sup>a/</sup> Rated on a scale of 1-5, in which 1 = extremely tight and 5 = extremely loose.

<sup>b/</sup> Rated on a scale of 1-5, in which 1 = no damage and 5 = all ears damaged.

### Distribution of High-Yielding Varieties with Good Husk Cover

The encouraging results of this study have prompted CIMMYT maize breeders to make the best of the materials tested widely available to other researchers. Toward that end the remnant seed of the best S<sub>1</sub> lines identified in the study are being 1) used for recombination to form the next cycle of pool 20, 2) selfed by CIMMYT and its cooperators to produce inbred lines, and 3) recombined to form synthetic

varieties that can be used as breeding populations by national programs or as open-pollinated varieties. The syn.0 seed of these synthetic varieties (see the data on S<sub>1</sub> performance in Table 6) is being produced during the winter season of 1985 at Poza Rica, and syn. 1 will be available in sufficient quantities for testing late in the same year. The varieties should give good yields, show excellent husk cover and extension, and be quite uniform in maturity and ear height.

Table 6. S<sub>1</sub> lines with perfect husk cover selected to form synthetic varieties

S <sub>1</sub> line no.	Grain yield (t/ha)	Poor husk cover (0/o)	Husk tightness rating <sup>a/</sup>	Ear insect rating <sup>b/</sup>	Husk extension (cm)	Days to silk	Ear height (cm)
<b>Pool 20</b>							
176	3.47	0.0	2.5	1.7	7.0	54	99
277	3.16	0.0	2.2	1.8	6.8	57	92
353	3.06	0.0	1.8	1.8	6.4	56	97
88	4.18	0.0	3.5	2.8	6.3	57	93
42	3.41	0.0	2.3	1.7	9.6	55	93
Selected mean	3.46	0.0	2.5	2.0	7.2	56	95
Pop. mean	3.03	10.4	2.9	2.2	5.1	56	88
<b>Population 21</b>							
171	4.42	0.0	2.5	2.0	8.8	64	88
28	3.47	0.0	2.5	1.3	5.9	63	80
347	3.37	0.0	2.7	2.0	6.8	63	88
87	3.71	0.0	2.7	2.0	5.1	65	79
74	2.95	0.0	2.8	2.5	6.4	66	87
Selected mean	3.58	0.0	2.6	2.0	6.6	64	84
Pop. mean	3.23	10.5	2.5	2.1	4.9	66	83

<sup>a/</sup> Rated on a scale of 1-5, in which 1 = extremely tight and 5 = extremely loose.

<sup>b/</sup> Rated on a scale of 1-5, in which 1 = no damage and 5 = all ears damaged.

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## Boosting Protein Quality in Maize

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Maize scientists have long had a keen interest in improving protein quality in the crop, but until about 20 years ago all attempts to do so either failed or produced only meagre gains. Though not nearly as deficient in this respect as some other staple foods, such as cassava, maize does have a low protein content (about 9%), and roughly half of that contains no lysine and tryptophan, the two most important of the essential amino acids. The first major breakthrough was the discovery in 1963 that the mutant maize gene opaque-2 raises lysine and tryptophan content; researchers have since learned that other mutant genes (opaque-7 and floury-2) have the same effect.

In several research programs around the world, these genes were introduced into promising maize genotypes with high hopes of eventually bringing about substantial improvement in the nutritional welfare of maize consumers in developing countries. But, as is all too often the case in plant breeding, a highly desirable characteristic turned out to be closely associated with several undesirable ones. Tests of high-lysine varieties and hybrids showed that they were largely unacceptable to farmers because their grain was dull and chalky in appearance

rather than hard and vitreous, as is generally preferred; high-lysine materials also gave lower yields than their normal counterparts, were more susceptible to ear rots and insect pests of stored grains, and dried more slowly.

These formidable obstacles dampened the general enthusiasm about high-lysine maize, prompting some programs to curtail their work on these materials and others to abandon it altogether. Rather than retreat from what seemed such a promising avenue of research, scientists at CIMMYT judged that the problems were not insurmountable and continued working toward the goal of developing acceptable high-lysine maize.

Events of the last few years have indicated that this judgment was essentially correct. Solutions to the problems preventing widespread adoption of what is now called "quality protein maize" (QPM) have been found and successfully applied, with the result that several developing countries are about to engage in commercial use of QPM germplasm.

### **A Change in Breeding Strategy**

Much of the recent progress achieved in QPM germplasm development can be attributed to timely changes in breeding

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strategy. Initially, quality protein maize materials were developed at CIMMYT using only the opaque-2 gene. Later, however, the breeding strategy was modified to include a combination of two genetic systems: the opaque-2 gene and a myriad of modifying genes associated with the opaque-2 locus. This change in strategy led to the conversion of soft chalky opaque-2 kernels into vitreous normal-looking kernels. By using this modified approach in the conversion program and in the development and improvement of broad-based QPM composites,

center researchers were able to produce a rich array of QPM germplasm to meet the needs of important maize-producing areas in the developing world.

Once it was recognized that this approach had served its purpose, the program took a new tack. All the available QPM germplasm was merged into special QPM pools and populations. By 1984 seven tropical and six subtropical QPM pools had been developed, and the number of populations had risen to six tropical and four subtropical ones. An important part of the new



Through innovative breeding approaches, CIMMYT scientists have developed maize varieties that combine quality protein with good yields and an almost completely normal grain type.



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strategy was to handle the QPM pools and populations in homozygous opaque-2 backgrounds (for accelerating the accumulation of favorable modifier genes and improving kernel phenotype, resistance to ear rots, and other agronomic characteristics) and to improve the germplasm through intrapopulation schemes in much the same manner as normal materials.

By means of a modified ear-to-row half-sib system, most of the QPM pools have been improved considerably for several traits. The latest cycles of selection have somewhat lower plant and ear heights, earlier maturity, and substantially better kernel phenotype than the original cycle. Only modest gains have been made in yield, however, owing to mild selection and the heavy emphasis placed on modifying the kernels without reducing protein quality. According to the most recent analyses, protein quality has remained virtually unchanged.

The QPM populations are being improved through CIMMYT's International Progeny Testing Trials (IPTTs), with emphasis on accumulation of genetic modifiers, stability of these modifiers, ear rot resistance, and maintenance of protein quality. On the basis of IPTT results, numerous experimental varieties have been developed and are now being evaluated.

### **Advances in QPM Improvement**

Improvement in yield, kernel phenotype, and resistance to ear rots has received particular emphasis in CIMMYT's QPM work, since deficiencies in those characteristics were the principal barriers to acceptance and commercial use of high-lysine maize. Progress in correcting these deficiencies is described in the following sections.

**Yield performance**—Many possible approaches have been tried, both singly and in combination, to improve the yield of QPM. The primary tactics have been to select for greater kernel weight in segregating generations, discard ears exhibiting poor dry matter accumulation in the grain, carry out recurrent selection, and harden the endosperm through accumulation of genetic modifiers.

Over the years these techniques have brought about continuous improvement in yield and other agronomic traits of almost all the QPM gene pools, and this improvement is clearly reflected in more advanced materials. Several QPM experimental varieties, for example, performed just as well as the normal checks during 1983 in EVT-15A and EVT-15B, results of which are given in Table 7.

Equally encouraging results have been obtained from other tests. In a trial conducted in Guatemala during 1983, the QPM variety Nutricita, which has already been released in the country, yielded about as much as some of the best experimental varieties and hybrids (Table 8). In China Tuxpeño-1 H.E.o<sub>2</sub> has given yields as high as those of Tuxpeño-1 normal, and in Mexico's national uniform trials, three other QPM materials (La Posta QPM, Obregon 7740, and Tuxpeño-1 QPM) performed similarly to two hybrids and one variety that are being marketed in the country. All of the materials in this trial, however, yielded less than Poza Rica 7822.

**Table 7. Performance of QPM in experimental variety trials, 1983**

Entry	Mean yield (kg/ha)	% of normal check
<b>EVT 15A (25 locations)</b>		
Across 8039	4077	98
Poza Rica 8140	4546	110
Across 8140	4443	107
Across 7726 normal (check)	4145	100
<b>EVT 15B (8 locations)</b>		
Tlaltizapan 8141	5195	105
Across 8141	4978	100
Across 7941 (check)	4809	97
Antalaya (1) 8141	4711	95
Across 7845 normal (check)	4967	100

**Kernel modification**—In spite of the large number of genetic modifiers controlling kernel modification in opaque-2 maize, steady progress is being achieved in every cycle of selection. Stable modification has been attained at the ear level, but within-ear variability persists. It will probably take additional cycles to produce a completely normal phenotype. Since most QPM materials are following a similar improvement trend, further modification in kernel phenotype should be accompanied by a reduction of within-ear variability for this trait.

The advances made in eight cycles of selection are well represented by changes in the frequency of the various scores for kernel modification, which is rated on a scale of 1-5, with 1 indicating that kernels are completely vitreous and

**Table 8. Performance of variety Nutricita in a Central American Regional Variety Trial, 1983**

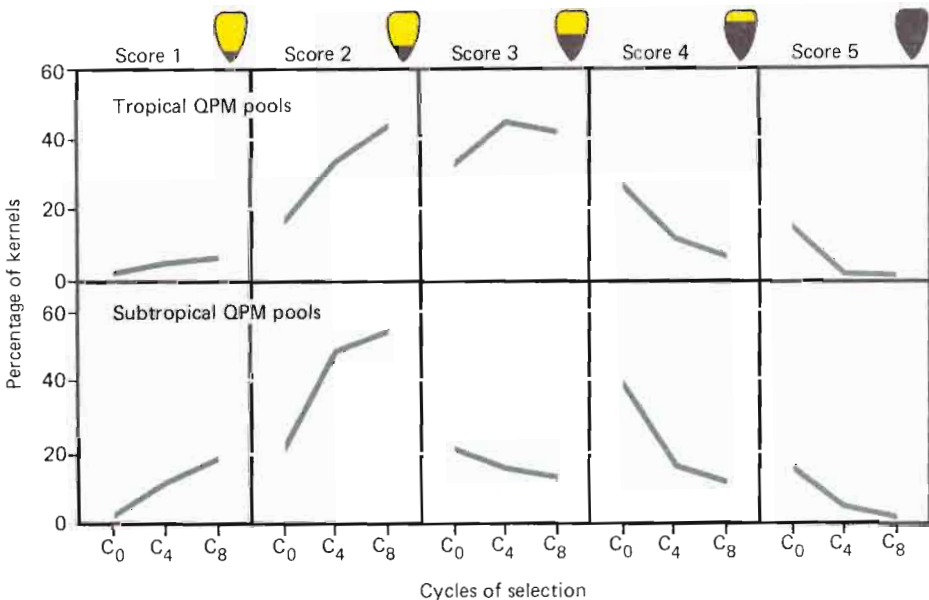
Entry	Yield (kg/ha)	Percent of check
ICTA-B <sub>1</sub> (normal)	5235	98
Nutricita	5298	98
CENTA H <sub>5</sub> (check)	5397	100
Diamantes 8043	5248	97
Tocumen 7428	5095	94
La Maquina 7727	4780	88
ICTA HB-83	6189	114
CENTA HE 20	6008	111

5 that they are completely soft (Figure 2). The frequency of the scores has changed dramatically; 4 and 5 have practically disappeared, and 1 and 2 are gradually increasing.

**Ear rot resistance**—Though some QPM materials still show higher incidence of ear rots than their normal counterparts, resistance to these diseases has been gradually increasing, partly as a result of improvement in kernel phenotype and better drying. Resistance has also been improved immensely through reduction in the frequency of undesirable genes that are responsible for pericarp splitting, which leads to secondary infection by ear rots.

In the improvement of QPM pools and populations, ear rot is heavily stressed in field selection and in selection based on trial data. Particularly good progress has been made in the IPTTs by selecting resistant families from advanced QPM populations at locations where the incidence of ear rot is quite high. In addition, some pools and populations are being artificially inoculated with ear-rotting organisms to enhance the resistance of these materials.

Tests of QPM germplasm have given quite positive results. In EVT-15A and EVT-15B, conducted during 1983, there was little or no difference between QPM materials



**Figure 2. Changes in the frequency of kernel modification scores over various cycles of selection**

and their normal counterparts in ear rot incidence (Table 9). The QPM entries do, however, show slightly higher incidence of the disease at locations where infection is severe.

### Use of QPM Germplasm in National Programs

The combination of superior protein quality and acceptable agronomic characteristics in CIMMYT's QPM germplasm has generated new interest in this material both in the public and private sectors. Examples are given below of the various uses to which some countries around the world are putting QPM germplasm.

**Table 9. Ear rot data for QPM in experimental variety trials, 1983**

Entry	Ear rot (°/o)
<b>EVT 15A (22 locations)</b>	
Poza Rica 8140	15.2
San Jeronimo (1) 8140	12.8
Across 7940 QPM (check)	13.5
Across 7926 normal (check)	15.1
Local check mean (normal)	13.1
<b>EVT 15B (7 locations)</b>	
Tlaltizapan 8141	1.5
Across 8141	1.4
La Platina 7941	2.3
Across 7845 normal check	2.7
Local check mean (normal)	1.2

In Mexico numerous trials have been conducted to evaluate tropical, subtropical, and highland QPM materials, some of which, most notably Composite I, Puebla opaque-2, and a highland modified opaque-2 composite, are being grown on a small scale by farmers in the state of Michoacan. Other materials, Tuxpeño-1 QPM and Poza Rica 8140, are being multiplied for swine feeding trials. A nationwide bread company has shown a strong interest in using high-lysine maize and is increasing population 68, Guanacaste 7940, Tuxpeño-1 QPM, and Poza Rica 8140 under contract with maize growers.

In Guatemala, as mentioned previously, an open-pollinated QPM variety, Tuxpeño-1 H.E. 02, has been released to farmers as Nutricia. Efforts are underway to produce enough seed for planting this variety on more than 1000 ha. Using the same source population, Guatemalan researchers have developed new superior varieties that may be more uniform, have better husk cover, and give higher yields.

Scientists in other countries of the Central American and Caribbean region are also at an advanced stage in their QPM work. Costa Rica, Panama, and the Dominican Republic all have inbred lines derived from QPM pools and

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populations. Researchers are evaluating these lines for combining ability and subsequent formation of hybrids. In Honduras Tuxpeño-1 H.E.02 has been multiplied on 2 ha for extensive testing in on-farm trials.

Many other promising developments are taking place in South America. The experimental variety Across 7740 has performed well in Venezuela and is being multiplied for planting on about 1000 ha. New selections from the same source population are now available that give a higher yield and have better kernel phenotype and harder flinty texture, making them better suited for preparing "arepas." Milling tests are being performed to confirm the suitability of the materials for this maize preparation.

In Bolivia the QPM varieties Tuxpeño opaque-2 and Chuquisaca 7741 are being grown on a small scale primarily for swine production. Argentina is also exploring the possibility of using QPM materials for this purpose and has increased some CIMMYT materials for swine feeding trials. In addition, private seed companies in some South American countries are developing QPM lines through conversion programs, using CIMMYT germplasm as donor stocks. Maize breeders in Brazil

have also used this material extensively in combining ability tests and in deriving QPM inbred lines for hybrid development.

Renewed enthusiasm for high-lysine maize is by no means limited to Latin America. In Senegal seed of the QPM materials Obregon 7740 and Temperate White QPM is being increased and widely evaluated in on-farm tests and will probably be recommended for large-scale adoption by farmers.

QPM materials are also thriving in China, particularly in the southern part of the country, where Tuxpeño-1 QPM has yielded as well and sometimes better than its normal counterpart. Having started with just a small quantity of seed of this variety (which the Chinese have designated Tuxpeño-102 to distinguish it from the normal counterpart), breeders are now growing 10 ha for seed increase and are rapidly multiplying Tuxpeño-102 for distribution to farmers. This variety has also been evaluated in swine feeding trials, with quite favorable results. In northern China, which has a more temperate climate, inbred lines are being extracted from CIMMYT's tropical and subtropical QPM germplasm, and one of these is already being used in a hybrid.

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## Measuring the Progress of Population Improvement

The final test of progress in CIMMYT's population improvement scheme is the degree to which it benefits national programs and the farmers they serve. Center scientists attempt to gauge the benefits accruing to national maize breeders and farmers by maintaining close contact with research cooperators around the world. As a further check on the effectiveness of the Center's approach in population improvement, several staff members of the Maize Program have recently subjected it to a more systematic evaluation. Their results indicate that full-sib family selection and multilocational testing are effective in improving yield and other traits, including tolerance to some stresses.

### Research Methods

CIMMYT's systematic population improvement program, using standard full-sib family selection and international testing of full-sib progenies, was begun in 1974. Initially, one improvement cycle was completed each year. With this approach, referred to as System 1 for the purposes of this study, 250 full-sib families were formed in the

winter season (November to April) in Mexico and during the following season were sent for testing, in comparison with six local checks, to six locations in the northern and southern hemispheres.

While these trials were being grown in the northern hemisphere, where the main maize growing season is April to September, the full-sib families were also being evaluated in Mexico in disease, insect, and high-density nurseries. Families in the disease nursery were rated for their response to stalk and ear rots under artificial inoculation, those in the insect nursery for fall army worm damage under artificial infestation, and the ones planted at high density for yield, barrenness, and lodging.

Based on the results of the international trials conducted in the northern hemisphere and data from the stress nurseries, about 40% of the superior full-sib families were selected. During the next growing season, reciprocal plant-to-plant crosses were made between plants of these families (some families could be discarded at this stage on the basis of data received by flowering time from some sites in the southern hemisphere), and at harvest 250 pairs of full-sibs were selected for the next cycle of evaluation.

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A serious drawback of this system was that it did not permit full use of data from test locations in the southern hemisphere, where the main maize-growing season is September to April. For that reason, the system was modified in 1977 at the beginning of the third selection cycle in such a way as to complete one cycle in four seasons. This modified system of full-sib family selection with multilocational testing is the one CIMMYT now uses in its population improvement program and is referred to here as System 2.

In System 2 the 250 full-sib families that make up each International Progeny Testing Trial (IPTT) are developed in the winter season (October to April) in Mexico, and the trials are dispatched to test locations both in the northern and southern hemispheres. In the northern hemisphere (including Mexico), IPTTs are conducted in the summer season (May to September). During the following season, while the same trials are being grown at locations in the southern hemisphere, the 250 full-sib families of each IPTT are planted in breeding nurseries at CIMMYT in Mexico. About 50% of the desirable plants in each family are selfed, and at harvest two or three ears are selected from each family,

mainly on the basis of a single major trait, such as insect or disease resistance, or other characteristics such as maturity and height.

During the summer season in Mexico (May to September), each S<sub>1</sub> ear identified with its parental family is planted ear-to-row. By flowering time, data from IPTTs conducted in the southern hemisphere generally have been received, and based on the results from all successful IPTTs about 100 full-sib families are selected. The best S<sub>1</sub> families derived from these selected families are identified (based on some major trait), and the selected plants (approximately 50%) are bulk-pollinated. At harvest two or three half-sib ears are selected corresponding to each of the selected full-sib families, and seed from these ears is planted ear-to-row during the next season. The superior half-sib families are identified and reciprocal crosses made among them to generate full-sib families for the next cycle of testing. In doing so CIMMYT breeders try to ensure that the two half-sib families in a cross come from different full-sib families.

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In 1983 and 1984, three cycles (C<sub>0</sub>, C<sub>2</sub>, and the last cycle) of the eight full-season (late maturing) lowland tropical populations listed in Table 10 were compared to measure the progress achieved through selection.<sup>1/</sup> Germplasm from CIMMYT gene pools was introgressed into the six populations that are marked with an asterisk in the table. Four replications of each trial, which had a split-plot design with populations as main plots and cycles as subplots, were grown during 1983 and 1984 in six environments, three of them in Mexico and one each in Colombia, Guatemala, and Honduras.

### Research Results

The average performance of each population and cycle over all locations is given in Table 10. Mezcla Tropical Blanca was the highest yielding population and Amarillo Cristalino-1 the lowest. The earliest population was Cogollero and the latest La Posta, which was also significantly taller than the other populations.

On the average, for all populations and locations, C<sub>2</sub> was significantly earlier and shorter than C<sub>0</sub> but similar to it in every other trait. Generally, the last cycle of

selection was significantly better than both C<sub>0</sub> and C<sub>2</sub> in most characters.

System 2, with its two-year improvement cycle, has been quite effective in improving all the traits and achieved distinctly better progress per cycle in yield than System 1. Whereas in the first system three populations had reductions in yield and only one had an increase, with System 2 no population showed a yield loss and five made large gains (Table 11). The difference in gain per cycle between the two systems can be attributed to the more complete use in System 2 of data from both the northern and southern hemispheres and the within-family selection practiced in this system. Part of the improvement in yield may also be attributed to the introgression of superior germplasm into six of the populations from the corresponding back-up gene pools.

Both systems have been effective in reducing days to silk, plant height, and ear height, although System 2 achieved more rapid progress in these traits than System 1. In the improvement of ear aspect and number of ears per plant, progress per cycle has been much greater with System 2 than with System 1. In fact, with System 1 ear aspect deteriorated in four populations and remained the same in the others, whereas with System 2 this trait improved in all populations except one.

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<sup>1/</sup> For a full description of these populations, see *CIMMYT Report on Maize Improvement, 1980-81*.



**Table 10. Mean performance for three cycles of eight tropical maize populations at six locations**

Populations	Cycles	Yield (kg/ha)	Days to silk	Plant height (cm)
Tuxpeño 1	C <sub>0</sub>	5975	65.5	212
	C <sub>2</sub>	6041	65.3	208
	C <sub>5</sub>	6335	66.4	220
	$\bar{X}$	6117	65.8	213
Mezcla Tropical Blanca	C <sub>0</sub>	6090	67.6	226
	C <sub>2</sub>	6502	66.1	226
	C <sub>4</sub>	6548	65.3	220
	$\bar{X}$	6380	66.3	224
Antigua Veracruz 181	C <sub>0</sub>	5682	66.8	226
	C <sub>2</sub>	5327	67.3	214
	C <sub>5</sub>	5763	66.0	214
	$\bar{X}$	5590	66.7	218
Amarillo Cristalino-1	C <sub>0</sub>	5267	67.5	226
	C <sub>2</sub>	5275	66.9	232
	C <sub>5</sub>	5751	65.7	220
	$\bar{X}$	5431	66.7	226
Amarillo Dentado	C <sub>0</sub>	6021	67.5	238
	C <sub>2</sub>	6028	66.0	226
	C <sub>4</sub>	6386	65.1	220
	$\bar{X}$	6145	66.2	228
Tuxpeño Caribe	C <sub>0</sub>	6201	66.7	224
	C <sub>2</sub>	6009	66.3	220
	C <sub>5</sub>	6213	64.5	207
	$\bar{X}$	6141	65.8	217
Cogollero	C <sub>0</sub>	5706	66.1	234
	C <sub>2</sub>	5570	65.8	232
	C <sub>5</sub>	6248	63.2	213
	$\bar{X}$	5842	65.1	226
La Posta	C <sub>0</sub>	6124	69.6	248
	C <sub>2</sub>	6262	69.0	244
	C <sub>4</sub>	6578	67.0	233
	$\bar{X}$	6322	68.6	241
LSD (.05) between populations		230	0.7	4
LSD (.05) within populations		314	0.8	6

The general lack of progress with System 1 can be explained by its inability to take advantage of information from all test sites and the absence in this system of selection within families. Selection among families was about the same in the two systems, but in System 2 selection within families was about 6%, giving an overall selection differential of 1.92 standard deviation units and resulting in improvement of all traits.

Contrary to the results of several other researchers, the CIMMYT populations became earlier and

shorter at the same time that yields increased. These improvements in yield were generally associated with increased numbers of ears per plant, a characteristic that is known to improve stress tolerance in maize and consequently its yield stability.

Stability analyses (the results of which are given in Table 12) suggest that the CIMMYT populations were quite stable not only in yield, but in days to silk and plant height. For most populations and cycles, the *b* values were close to 1.0, and *SD*<sup>2</sup> values were generally insignificant.

**Table 11. Percent progress per cycle for six traits in eight tropical maize populations**

Populations	Yield		Days to silk		Plant height	
	Sys. 1	Sys. 2	Sys. 1	Sys. 2	Sys. 1	Sys. 2
Tuxpeño 1	0.55	1.62	-0.15	0.56	-0.80	1.82
Mezcla Tropical Blanca	3.38	0.35	-1.11	-0.61	0.00	-1.29
Antigua Veracruz 181	-3.12	2.73	0.37	-0.64	-2.76	0.00
Amarillo Cristalino-1	0.07	3.01	-0.44	-0.60	1.19	-1.73
Amarillo Dentado	0.06	2.97	-1.11	-0.68	-2.44	-1.37
Tuxpeño Caribe	-1.55	1.13	-0.30	-0.90	-0.76	-2.04
Cogollero	-1.19	4.06	-0.23	-1.32	-0.44	-2.73
La Posta	1.13	2.52	-0.43	-1.45	-0.83	-2.20
Mean	-0.08	2.30	-0.42	-0.71	-0.86	-1.19
Populations	Ear height		Ear aspect		Ears per plant	
	Sys. 1	Sys. 2	Sys. 1	Sys. 2	Sys. 1	Sys. 2
Tuxpeño 1	-0.89	1.21	0.00	-3.51	0.52	-0.34
Mezcla Tropical Blanca	-1.18	-2.02	0.00	-2.70	0.53	1.05
Antigua Veracruz 181	-3.94	0.00	4.29	-2.63	-0.69	0.71
Amarillo Cristalino-1	1.25	-1.63	2.78	-3.51	0.00	2.13
Amarillo Dentado	-2.63	-4.36	1.43	0.00	-1.52	4.17
Tuxpeño Caribe	0.83	-3.01	2.70	-2.56	-0.54	1.09
Cogollero	-1.84	-4.33	-0.24	-4.27	2.69	0.34
La Posta	-1.37	-4.23	0.00	-2.78	2.75	1.04
Mean	-1.22	-2.30	1.37	-2.74	-0.47	1.27

Full-sib recurrent selection is clearly effective in improving the performance of maize populations, which in turn brings about proportionate gains in the performance of synthetics and lines derived from those populations. These findings have important implications for national maize programs, which are using

CIMMYT populations in a number of ways. Many are evaluating these through the Center's IPTTs; others are using experimental varieties developed on the basis of IPTT results; and some are developing hybrids directly or extracting inbred lines from superior full-sib families of the populations.

**Table 12. Stability analysis for three cycles of selection for yield, days to silk, and plant height**

Populations	Cycles	Yield		Days to silk		Plant height	
		b	SD <sup>2</sup> x 10 <sup>4</sup>	b	SD <sup>2</sup>	b	SD <sup>2</sup>
Tuxpeño 1	C <sub>0</sub>	1.00	2.64	0.99	-0.47	0.94	9.65
	C <sub>2</sub>	1.01	-1.98	0.98	-0.58	0.94	57.81*
	C <sub>5</sub>	0.99	10.82	1.02	-0.26	1.02	-12.68
Mezcla Tropical Blanca	C <sub>0</sub>	1.05	-8.00	1.02	-0.38	0.97	-3.22
	C <sub>2</sub>	1.12	1.83	0.99	0.05	0.94	-3.63
	C <sub>4</sub>	1.06	4.15	0.97	-0.51	0.94	23.42
Antigua Veracruz 181	C <sub>0</sub>	1.08	-3.94	1.01	-0.09	0.97	11.90
	C <sub>2</sub>	0.93	-3.61	0.99	1.26*	0.93	0.11
	C <sub>5</sub>	1.02	0.96	0.99	0.53	0.85	-10.81
Amarillo Cristalino-1	C <sub>0</sub>	0.78	35.66**	1.05	3.85**	1.03	29.73
	C <sub>2</sub>	0.99	32.72**	1.02	-0.18	0.97	-13.20
	C <sub>5</sub>	0.86	22.29**	0.99	-0.43	0.95	-16.96
Amarillo Dentado	C <sub>0</sub>	1.04	-4.25	1.00	-0.45	0.99	-27.33
	C <sub>2</sub>	1.11	-4.71	0.97	0.34	1.14	11.59
	C <sub>4</sub>	0.92	34.23**	0.96	-0.46	1.17	20.88
Tuxpeño Caribe	C <sub>0</sub>	1.10	1.33	0.96	-0.48	0.92	-19.75
	C <sub>2</sub>	0.93	-6.12	0.96	-0.37	0.95	34.23
	C <sub>5</sub>	0.91	17.95*	0.96	0.25	0.90	16.99
Cogollero	C <sub>0</sub>	1.14	11.34	0.98	-0.41	1.06	88.52**
	C <sub>2</sub>	0.89	36.16**	0.99	1.19*	1.20	6.18
	C <sub>5</sub>	0.92	2.53	0.94	-0.14	1.02	66.28**
La Posta	C <sub>0</sub>	1.11	11.00	1.08	-0.19	1.12	114.02**
	C <sub>2</sub>	1.06	10.33	1.07	-0.10	1.12	56.12*
	C <sub>5</sub>	0.97	3.21	1.06	-0.19	0.96	-16.39
LSD (.05) for cycles in a population		0.29		0.06		0.26	

\* Significant at the 0.05 level of probability

\*\* Significant at the 0.01 level of probability

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## Managing Germplasm Bank Materials

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Rapid progress in developing stable, high-yielding, stress-tolerant maize germplasm would be impossible if CIMMYT breeders did not have ready access to a wide range of genetic resources. This essential requirement is partially met for CIMMYT's researchers, as well as for other maize scientists throughout the world, by the Center's germplasm bank, which currently maintains 10,118 accessions of *Zea mays*, 2 of *Z. perennis*, 2 of *Z. mexicana*, 1 of *Z. luxurians*, and 86 unclassified teosintes. Over the last five years, 163 cooperators in 40 countries have requested a total of 3,727 accessions, amounting to more than one million seeds.

The germplasm bank accessions, so named following regeneration from the original collections, are of three types: collections, groups, and composites. Groups were formed from 1960 to 1963 by combining two or more collections of similar morphology and geographic distribution. One or more collections considered typical of members in a group were preserved as individual accessions, and the other components of the group were discontinued. In addition, some composites were formed on

the basis of special traits or racial criteria. Of CIMMYT's present accessions, about 94% are collections, 5% are groups, and the remaining 1% composites. Most of these accessions are from Mexico, Central America, South America, and the Caribbean.

All of this germplasm has been kept in two cold storage chambers, which have a combined volume of 244 m<sup>3</sup> and have been maintained, until recently, at 0-3°C with an average relative humidity of 32%. Since the seed will remain viable under these conditions for some 20 years, CIMMYT regenerates approximately 500 accessions annually according to priorities determined by the age, quantity, and viability of the seed. When possible, accessions are regenerated by growing 256 plants in 16 rows 5m long, using bulk half-sib pollinations and avoiding selfing. During this process, which requires about 4 ha of land and 125,000 hand-pollinations, agronomic data are recorded. Approximately the best 10% of the materials are selected for further evaluation and crossing with appropriate gene pools in the breeding program. The best of these materials are then selected for introgression into CIMMYT's breeding materials.

### Improvements in the Germplasm Bank Facility

In August 1984 CIMMYT began modifications in one of its cold storage rooms that will make it

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possible to keep the temperature at  $-15^{\circ}\text{C}$ . This improvement is expected to at least double the lifetime of the seed. Material could perhaps be kept viable for as long as 100 years in sealed packets containing samples of the accessions at reduced moisture. Such a large increase in seed longevity would reduce by at least half the number of regenerations required annually. The consequent increase in the period between regenerations (each of which results in some genetic drift) would keep the total change in the genetic composition of the accessions to a

minimum. The number of cycles of regeneration could be reduced even further by using seed from the sealed packets instead of the latest cycle of regeneration.

During 1985 seed of each accession will be divided and part placed in the intermediate storage bank, or working bank, and the remainder put under long-term storage in the modified facility. A computerized data management system, which catalogs and describes individual accessions, is being developed to improve access to the germplasm.



In CIMMYT's new system for regenerating germplasm collections, the accessions are first planted in observation rows to determine whether the site is suitable for regeneration. The plants in the photograph at left are well adapted to the site, those at right are not.

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### **Research and Evaluation Projects**

Since genetic resources are so vital to CIMMYT's work, the Center has a strong interest in conducting research and evaluation projects that will result in better management and exploitation of the germplasm. Increased financial assistance for the germplasm bank made it possible to initiate several new research projects in 1984.

### **A new system for regenerating germplasm collections**

—Some of the collections, particularly from the highlands, have not been regenerated successfully because we have lacked sufficient information for choosing appropriate regeneration sites. When materials have been grown for regeneration at a site to which they were not adapted, either they have been lost or suitable regenerations have not been obtained.

With the new system, before any effort is made to regenerate an accession, it is first planted in observation rows at the sites considered most appropriate to determine which are actually suitable for regeneration (see accompanying photographs). If the material is sufficiently adapted,

plant-to-plant crosses are made within the row. The seed so produced is planted again the next year, alongside the residual original seed, for regeneration. Should there not be enough plants for regenerating a collection from the original seed, the plants grown from fresh seed—produced in the observation row—can be used as females and pollinated with bulk pollen from the limited number of plants derived from the original collection. This procedure ensures better representation of the original collection and guards against its loss.

In some cases, the sites chosen for observation rows prove unsuitable for regeneration of the accessions, and it becomes necessary to select a more appropriate location based on data from the observation row. To determine how best to use this information, a preliminary trial of lowland tropical, subtropical, and temperate materials, together with highland materials from Mexico, Peru, and Ecuador, was grown at several locations in Mexico during 1984 (the project will be expanded in 1985). The results obtained so far indicate that several plant characters—based on the morphological response of materials grown in environments to which they are only partially or not at all adapted—might be useful for

predicting whether particular regeneration sites are suitable. The number of leaves below the ear, for example, appears to change in a predictable way in lowland tropical and Mexican highland tropical maize materials grown at sites to which they are not adapted. This number increases by an average of 35% when lowland tropical materials are grown in the highlands or when highland materials are grown in the lowlands at the same latitude and planting date (Figure 3).

The Andean highland materials from Peru and Ecuador, when grown in Mexico, generally have more than the maximum number of leaves produced by materials that are adapted to Mexican highland locations, indicating the Andean

highland materials' basic lack of adaptation in Mexico. CIMMYT is therefore undertaking collaborative work with national programs outside Mexico to regenerate collections that are not sufficiently adapted to conditions in this country.

Highland and lowland tropical materials also differ significantly in their heat unit requirements for flowering (Figure 4). Even from data recorded at only one observation site, it is possible to distinguish between tropical highland and tropical lowland maize. The heat unit requirements of materials from Peru and Ecuador clearly indicate their highland origin. Other characters, such as ear leaf length and breadth, do not appear to vary significantly across

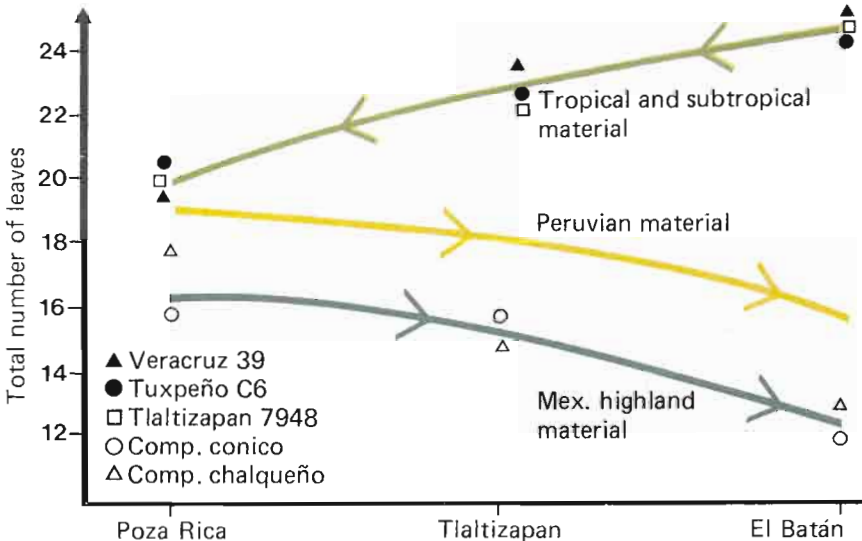


Figure 3. Leaf numbers of various materials grown at three locations in Mexico. The arrows indicate increasing adaptation

environments and hence are not useful for choosing possible regeneration sites. This finding does indicate, however, that evaluation of traits related to these characters can be done in any of the environments.

Data collected from observation rows of original collections on plant characters such as heat unit requirements and total number of leaves should be extremely helpful in selecting sites for suitable regeneration. Finding appropriate sites will be especially crucial for collections with little passport data and for which only a small quantity of seed is available.

**Creating adequate conditions for germplasm regeneration**—CIMMYT is attempting to reduce genetic drift resulting from natural selection by

making the environment for regeneration of materials as nearly neutral as possible (through such means as protecting materials against diseases and insects). Maintaining a neutral environment has been particularly problematic in the regeneration of highland germplasm, which can be so severely damaged by fungal ear rots that not a single ear is harvested from susceptible material. Methods of protecting materials against ear rots and insects during regeneration are currently being evaluated.

**Effects of seed age**—Another study is being conducted in which old and new seed of several accessions are compared to gain a better understanding of the effects of seed age. Reduced vigor in old seed is a serious problem in evaluating or

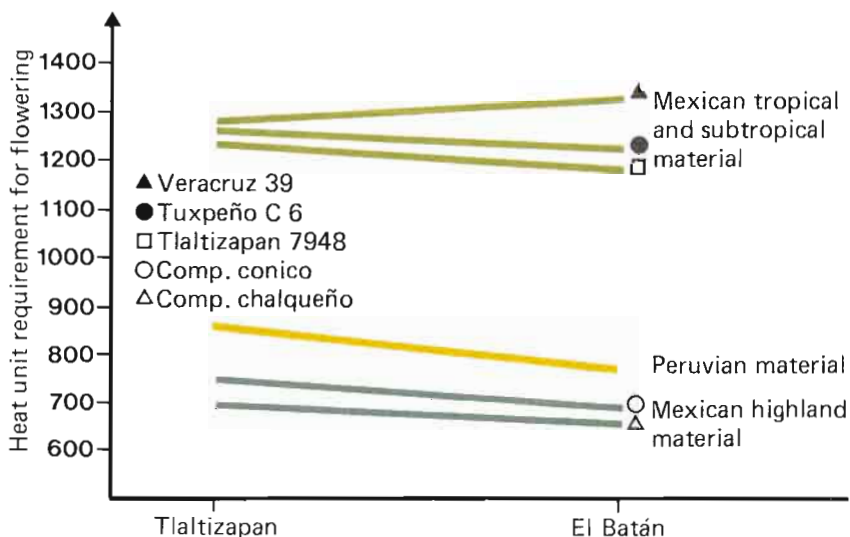


Figure 4. Heat unit requirements for flowering of tropical, subtropical, and highland materials grown at two sites in Mexico



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regenerating accessions. Although seed remains viable (as indicated by germination tests), its ability to emerge and develop normally is reduced after a long period of storage. For example, the height of the base of the fifth leaf in seedlings derived from old seed is, on average, 21% less than the corresponding measurement in seedlings derived from new seed of the same accession. Also under investigation are the effects of seed age on plant type, vigor, and yield.

**Evaluation systems**—A major effort was begun in 1984 by the germplasm bank staff, working closely with maize breeders, to re-initiate evaluation of bank accessions for specific characters. For example, trials were conducted with bank accessions at several locations in Mexico to select germplasm for introgression into early and late pools, particularly for the highland valleys of Mexico, which comprise about 3 million ha. Some 728 accessions (from collections made between 1,700

and 2,700 m above sea level) were grown at 10 locations and were evaluated for yield and plant type in comparison with several check materials having early, late, and intermediate maturities. Some materials from the Mexican national maize program, together with 76 accessions (10.4% of the accessions evaluated) from CIMMYT's germplasm bank, showed excellent potential, and these will be recombined with other highland materials during 1985.

CIMMYT plans to expand its evaluations of germplasm bank materials in future years and is currently conducting trials that are a prerequisite for further disease and insect evaluation trials of bank accessions. The current trials should provide us with an approximation of the minimum number of plants required to estimate accurately the mean of an accession for each trait to be evaluated.



### Introduction

As CIMMYT's wheat program research agenda has evolved, the Center's operational philosophy and priorities have shifted in response to the changing needs of national crop improvement programs in developing countries. CIMMYT currently has a large array of experimental wheat germplasm, all of which has (in varying degrees) five basic characteristics: (1) high yield potential, (2) broad adaptation, (3) resistance to stem rust (*Puccinia graminis* f.sp. *tritici*), (4) resistance to leaf rust (*P. recondita*), and (5) resistance to stripe rust (*P. striiformis*). This extensive germplasm base is provided to developing countries through the Center's large international testing network. From this wealth of improved materials, national crop improvement programs make selections that are appropriate for their own production conditions.

Today, approximately 45 million hectares in developing countries are devoted to CIMMYT-derived wheat germplasm, with another 10 to 15 million hectares in developed countries. Clearly, the germplasm

developed to date has had a very significant impact on wheat production around the world; its broad adaptability and high yield potential have made it particularly useful under diverse production conditions.

Even with this success, however, much breeding research is still to be done. The development of this broadly adapted germplasm base has allowed CIMMYT breeders both the freedom to turn their attention to other factors limiting wheat production, as well as a firm foundation on which to build. In addition to improving and maintaining resistance to the rusts, efforts are underway to develop materials with improved resistance to many of the 40 species of fungi, bacteria and viruses known to attack small grain crops. Examples of such pathogens include *Helminthosporium* spp., barley yellow dwarf virus, *Fusarium* spp. and *Septoria* spp. Other research thrusts seek to develop varieties with greater yield potential and stability under such stress conditions as drought, temperature extremes and mineral toxicities.

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Many of these yield-limiting factors are not universal in nature, i.e., an important factor limiting production in one area or region may not be significant in other areas or regions. Thus, CIMMYT breeders are *not* attempting to build tolerances and/or resistances to these factors into its entire germplasm base. Rather, they are incorporating the desired traits into selected subsets of experimental materials that retain the broad adaptation, high yield potential, and resistance to the three rusts inherent in the entire germplasm base. This, then, is the CIMMYT approach to dealing with the need for germplasm with “specific” or “regional” adaptation.

The development of improved germplasm for these individual traits can have a significant impact on total world wheat production. It is also certain that, if we are successful in incorporating these characters, millions of small farmers who are currently living on some of the most marginal lands of the world will reap the benefits. CIMMYT cannot accomplish this goal alone. The Center relies on the cooperation of national crop programs in developing countries, and we need to tap the expertise of the scientific community in the developed countries of the world.

In the following pages, highlights of several of the Wheat Program’s ongoing research activities are described in some detail. While by no means a complete picture of all the crop research being conducted by Program staff, these highlights constitute a representative cross-section of the research agenda.

In this year’s report, the following research activities are highlighted:

- An analysis of the yield stability of CIMMYT’s high-yielding semidwarf bread wheat varieties, drawing on 15 years of data from the International Spring Wheat Yield Nursery;
- The improvement in the milling and baking quality of hexaploid triticales;
- Collaborative efforts with Argentinian scientists to develop a balanced program of fertilization for wheat grown in the Pampa Húmeda;
- Recent improvements in the leaf rust and scald resistance of CIMMYT’s barley germplasm.

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## Yield Stability of HYVs

As long ago as 1917, the yield stability of high-yielding varieties was discussed in the scientific literature.<sup>1</sup> As mankind came to rely increasingly on the use of improved cultivars for much of its basic food supply, the subject gained ever greater prominence in scientific circles.

This topic remains current, and today the discussion centers around the high-yielding germplasm developed and distributed by the international centers of the CGIAR system. Because of their high genetic yield potential, compared to the "traditional" cultivars, these genotypes are designated as "high-yielding varieties" (HYVs). This can be a misleading name, however, if used to characterize their actual performance rather than their yield potential, *per se*.

The rapid adoption of HYVs and more intensive farming practices in the Third World resulted in

considerable increases in food production. The "Green Revolution," a term that originated in the early 1970s, is used commonly to describe this period.

The spectacular increase in food production associated with the Green Revolution (which averted a Malthusian catastrophe, despite exponential increases in population) resulted from improving yields on the better soils, with the use of irrigation and chemical fertilizers. It is for this reason that popular scientific journals have often made the erroneous statement that HYVs only perform well under nearly optimum production conditions, and are inferior in yield compared to traditional or locally developed varieties (LDVs) under such production constraints as drought, diseases or low inputs.

There is a school of thought to which a minority of plant breeders now belong that believes in the basic tenet of breeding for local adaptation. These breeders endorse the hypothesis put forth by Grafius (2): "...it is always possible to find a locally adapted variety with a relative percentage yield, for a given environment, which is higher than or equal to the yield of the universal variety (one with a yield higher than or equal to the mean at all locations throughout the region)."

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<sup>1</sup> "Outside of the circles of plant breeders predominates the opinion that our high yielding varieties are less stable in yield performance compared to the old cultivars, thus showing larger average fluctuations in yield performance" stated Roemer (5) in his 1917 essay "Are the High Yielding Varieties more Stable in Yield?"

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In contrast, CIMMYT's wheat breeding strategy is to develop broadly adapted germplasm that performs exceptionally well in one or more ecological zones or regions, and that performs well under both high and low input conditions. In more technical terms, CIMMYT strives to develop germplasm with "spatial, temporal and system-independent" yield stability. In light of this strategy, the germplasm base of CIMMYT's wheat breeding program contains a wide range of broadly adapted materials, among which can be found lines and/or cultivars that are well adapted to specific environmental conditions.

The strategy of breeding broadly adapted germplasm is favored by the majority of plant breeders. In addition to the argument that a wide range of environments can occur even in a very small geographic area (or across years at the same site<sup>2</sup>), the tremendous costs inherent in developing a variety lends credence to the strategy of breeding broadly adapted materials. In developing countries, there is often no alternative other than a breeding

strategy based on broad adaptation, if breeding programs with limited resources are to breed for large geographical areas.

In this context of continuing concern about the reliability of broadly adapted HYVs, the yield performance, stability and adaptation both of HYVs and of LDVs was evaluated, using a global set of environments and different ecological zones and regional subsets. In contrast to the broadly adapted, high-yielding bread wheats developed by CIMMYT, the LDVs included in the study were bred for specific areas characterized by more or less homogeneous environmental conditions.

### **Research Methodology**

The analysis is based on data from the First to the Fifteenth International Spring Wheat Yield Nurseries (ISWYNs), which were distributed by CIMMYT from 1964/65 to 1978/79. The ISWYN is a standardized international yield nursery consisting of three replications of 49 bread wheat varieties and advanced lines, plus one local check. Since local checks frequently either were not identified by cooperators growing the trials, or were CIMMYT cultivars, they have not been used in most computations.

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<sup>2</sup> In the context of this study, the term "environment" is used to mean a set of specific production conditions prevailing at a given site during a given crop cycle. Hence over a 15-year period, a single site can constitute as many as 15 environments.

Table 1 shows how the genotypes were subdivided (according to their origins) into four different groups:<sup>3</sup>

- **Group I:** CIMMYT-bred cultivars released directly by national crop improvement programs.

<sup>3</sup> A detailed description of these groups can be obtained from Braun (1) and Pfeiffer (4).

- **Group II:** Initial crosses were made by CIMMYT, but at least one further selection was made in a national program.

- **Group III:** Locally developed cultivars with CIMMYT germplasm in their pedigrees.

- **Group IV:** Locally developed cultivars without CIMMYT germplasm in their pedigrees.

**Table 1. Number of genotypes, environments and locations, International Spring Wheat Yield Nursery (ISWYN), 1964/65 - 1978/79**

Group	Number of entries	Number of different genotypes
I Cultivars bred by CIMMYT, and named and released without further selection by a national program	249	103
II Cultivars whose early development was done by CIMMYT, but at least one further selection was made by a national program	178	57
III Cultivars whose parents are lines from group I and/or II. Varieties that were developed from crosses using CIMMYT germplasm	59	39
IV Cultivars that were developed without using germplasm derived from CIMMYT materials	198	70
Total number of entries	684	
Total number of genotypes		269
Total number of environments	973	
Number of different locations in 68 countries	240	

Table 2 gives the proportion of the four groups of materials in each ISWYN, as well as the number of nursery sets from which data were returned by cooperators for analysis. The changes in the composition of the ISWYNs reflect the acceptance and release of CIMMYT germplasm by national crop improvement programs.

The stability analyses were done using a model based on an assumed linear relationship between the performance of a variety and better growing conditions (i.e., it is assumed that varieties will yield more grain as the general production potential of the site increases, taking into account all production constraints).<sup>4</sup> The production potential of an

environment is indicated by its mean yield, which is the yield of all genotypes tested in that environment.

More specifically, the site means are shown on the X-axis, and the variety yields are shown on the Y-axis. The yield of a given variety at each site is used to calculate a regression line through the points that represent the performance of the respective genotype in each environment. The slope of this regression line measures the response of the variety to better growing conditions. The regression line that represents the average response of all entries included in the analysis of each variety has a slope of 1.00 (a 45° line). Thus, an above average yield response is indicated if the slope of the variety regression line is greater than 1.00. The greater the slope, the higher the responsiveness of the variety.

<sup>4</sup> The model used was a combination of those developed by Perkins and Jinks (3), Wright (7), and Utz (6).

**Table 2. Number of genotypes in groups I, II, III, and IV, ISWYNs 1 through 15**

Group	ISWYN number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
I	6	11	15	16	15	10	14	12	12	14	25	24	23	25	27
II	3	2	5	7	6	12	18	18	22	24	12	12	15	14	8
III	—	—	3	3	3	4	3	2	4	4	7	5	6	4	11
IV	15	11	26	23	25	23	14	17	11	7	5	8	5	5	3
No. of entries	24	24	49	49	49	49	49	49	49	49	49	49	49	48	49
No. of environments	34	47	61	63	63	60	66	81	69	68	65	76	76	71	73
ISWYN grand mean (t/ha)	2.7	2.8	2.8	2.9	2.6	2.8	3.6	3.6	3.9	3.5	3.8	3.9	3.3	3.5	3.8



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In addition, the sum of the squared deviations from the regression line can be used to describe the yield stability of a variety. The lower the sum of squared deviations, the higher is its yield stability (the predictability of its performance). However, as will be described later, this indicator can be misleading. To identify the best performing varieties across sites, both the variety mean and the parameters for stability and response must be considered.

A particular HYV is considered to have acceptable yield stability if (1) the mean yield is significantly higher than the average yield across sites, (2) the slope of the regression line is greater than or equal to 1.00, (3) the sum of the squared deviations approaches zero, and (4) the yield in the environment with the poorest production conditions exceeds or equals the average of all entries. This combination infers superior yield performance across the entire environmental range.

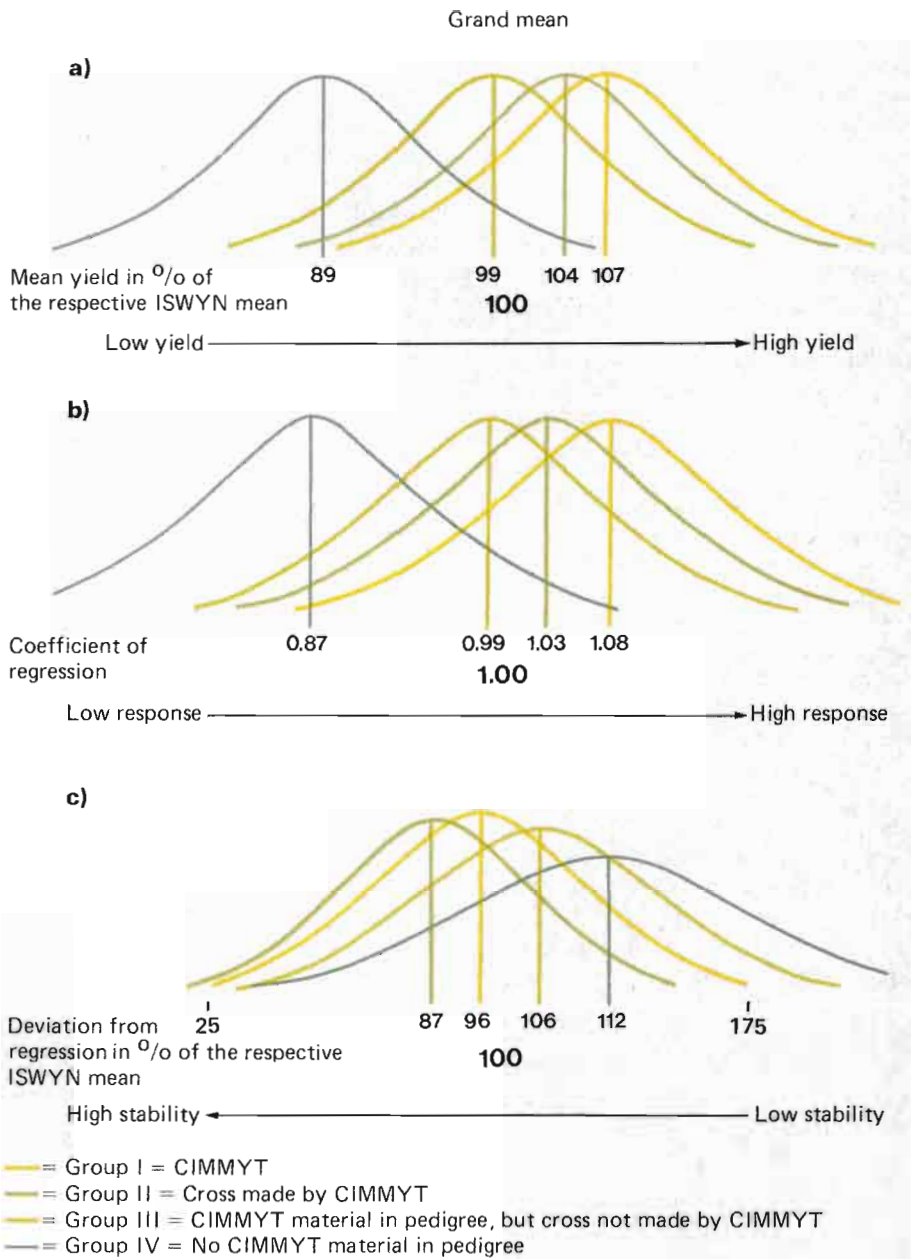
### Research Results

An indication of the adaptation of the genotypes can be obtained from Table 2. As the proportion of CIMMYT-developed Group I and II genotypes increased from 45% in the 6<sup>th</sup> ISWYN to 65% in the 7<sup>th</sup> ISWYN, with a corresponding decrease from 47% to 29% of the locally developed cultivars in group

IV, the ISWYN grand mean increased by about 30%. This was not due to a drastic change in sites, but rather to the replacement on a global level of low-yielding commercial cultivars with broadly adapted group I and II genotypes.

Figure 1 gives a more detailed picture of the mean yields, coefficients of regression and yield stability parameters for the four groups of genotypes. For each group, the relative values (means) of each parameter have been accumulated across ISWYNs 1 through 15. The broad variation evident in Figure 1 illustrates that each group contains high-yielding, highly responsive and highly stable genotypes. Since the large number of genotypes prohibits their consideration on an individual basis, the general response patterns of the groups will be emphasized here.

**Yield performance**—A comparison of the yield performance of the four groups clearly indicates the yield superiority of group I genotypes in each ISWYN. Thus, group I superiority is independent of the change over time in the composition of the nurseries (Table 2). Across the ISWYNs, yield differences remained constant (in absolute terms); the relative yield differences between groups decreased as the ISWYN mean yields steadily increased. Across



**Figure 1. Distributions of mean yields (a), coefficients of regression (b) and yield stability parameters (c) for four groups of genotypes across ISWYNs 1 through 15**

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the 15 ISWYNs, the following relationship among the groups holds true:

- Group I (CIMMYT-developed varieties) has significantly higher yields than the entries in group II (original crosses made by CIMMYT);
- Group II has significantly higher yields than group III (LDVs with CIMMYT germplasm in their pedigrees); and
- Group III has significantly higher yields than the varieties in group IV (LDVs with no CIMMYT germplasm in their pedigrees).

In general, then, the yield performance of the four groups across environments bears a positive correlation to the amount of CIMMYT germplasm contained in the pedigrees.

**Responsiveness to better growing conditions**—Similarly distinct results (clear group-specific differences), have been obtained for the coefficients of regression (bi). The bi values of all four groups are significantly different. The genotypes of groups I and II show an above average to high responsiveness to improved production conditions, whereas the cultivars of groups III and IV are below average in their responsiveness (Figure 1b).

This result has other implications: in the data of each of the 15 ISWYNs, a high positive correlation between the mean yield of the varieties and their coefficients of regression was obtained ( $\bar{r} = 0.84$ , significant at the 1% level). This means that high yield performance across environments can only be obtained using highly responsive varieties (those with high coefficients of regression).

**High-yielding vs. low-yielding varieties**—The strength of this correlation implies that above average mean yields and below average coefficients of regression rarely occur. Stated differently, it is very hard to find low-yielding varieties that perform better than the HYVs under poor production conditions, including low levels of inputs.

Much more frequently, below average mean yields are associated with below average coefficients of regression, i.e., when production conditions are poor, yields are low for all varieties. In the low-yielding environments, the differences in yield between HYVs and LDVs are very small. The low coefficients of regression associated with LDVs, which some people interpret as resulting from superior yield performance in poor environments, are actually due to their poor yield expression in high-yielding environments. In other words, the ISWYN varieties all yielded at about the same low level when production conditions were poor;

as production conditions improved, LDVs (with low coefficients of regression) were unable to respond, while HYVs (with higher coefficients of regression) were able to take advantage of the improved growing conditions. Thus, HYVs can be characterized both as “input efficient” and “input responsive.”

Occasionally, genotypes with high coefficients of regression produce high yields when production conditions are very favorable, and below average yields (lower than the LDVs) in poor environments. In

this analysis, such cases generally reflect a susceptibility to specific diseases present in the location, rather than a lack of input-efficiency, *per se*, in the HYV genotype.

Figures 2 and 3 illustrate the analysis of two input-efficient and input-responsive varieties, Nacozari 76 and Veery “S”. These varieties have high genetic yield potential and exhibit superior yield performance across the entire range of environments. In the case of Nacozari 76 (Figure 2), note that

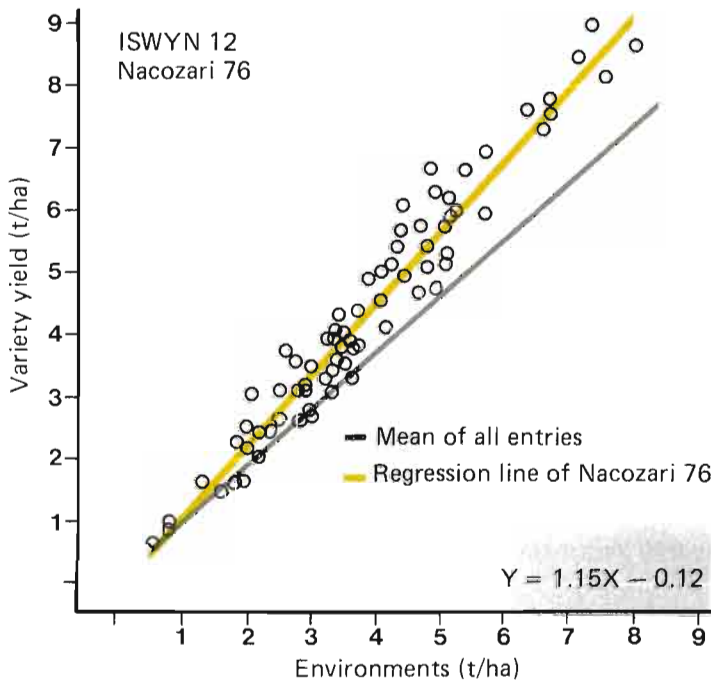


Figure 2. Yield of Nacozari 76 in 76 environments of the 12<sup>th</sup> ISWYN (Pfeiffer, 1984)

in poor environments its yield is not very different from the mean of all entries, but that as production conditions improve its yield becomes significantly greater than the average. In the case of Veery "S", note that its yield is better than the mean of all entries in nearly all environments. Its coefficient of regression is not much higher than that for the mean of all entries, but its yield is consistently above the mean yield of all entries, indicating significantly superior yield performance in all environments. These two varieties

represent "true" HYVs, the types that result from CIMMYT's breeding strategy.

**Yield stability**—It is evident from Figure 1c that each of the four groups contains genotypes having stable yields, as well as some having unstable yields. Analyses of the data show that group II is significantly more stable than groups I, III and IV. CIMMYT-bred genotypes (group I) have the same stability as group III and are significantly more stable than IV. However, considering yield stability

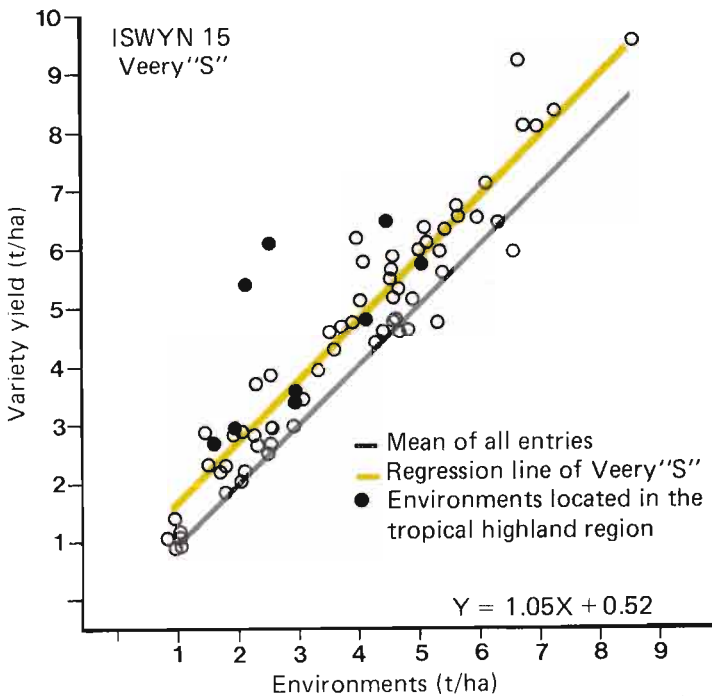


Figure 3. Yield of Veery "S" in the 73 environments of the 15<sup>th</sup> ISWYN (Pfeiffer, 1984)

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alone when examining these four groups is not sufficient to decide what is and what is not a “good” genotype; desirable genotypes must combine high yield stability with high yield potential, high input-efficiency and high input-responsiveness.

The tendency for higher instability among the group IV entries is caused to a certain extent by a high proportion of genotypes having very low yield stability due to late maturity, photo-period sensitivity and/or some vernalization requirements. The grand mean might therefore be somewhat biased. Furthermore, the fact that group II shows a slightly higher yield stability than group I may be misleading, since the yield stability of some outstanding group I genotypes is underestimated (this will be discussed in a moment).

Since critics state that HYVs are less stable than LDVs, the relevant question is whether the high mean yields of the HYVs are correlated with yield stability. In fact, a significant correlation on a global level between grain yield and yield stability parameters has been found in 9 of 15 ISWYNs. The average correlation coefficient is negative (-0.46, significant at the 1% level). Low deviation from the regression line indicates genotypic yield stability; therefore a negative correlation of these two factors indicates that genotypes with high yields exhibit a high yield stability, a conclusion that holds true not only on a global basis, but also on

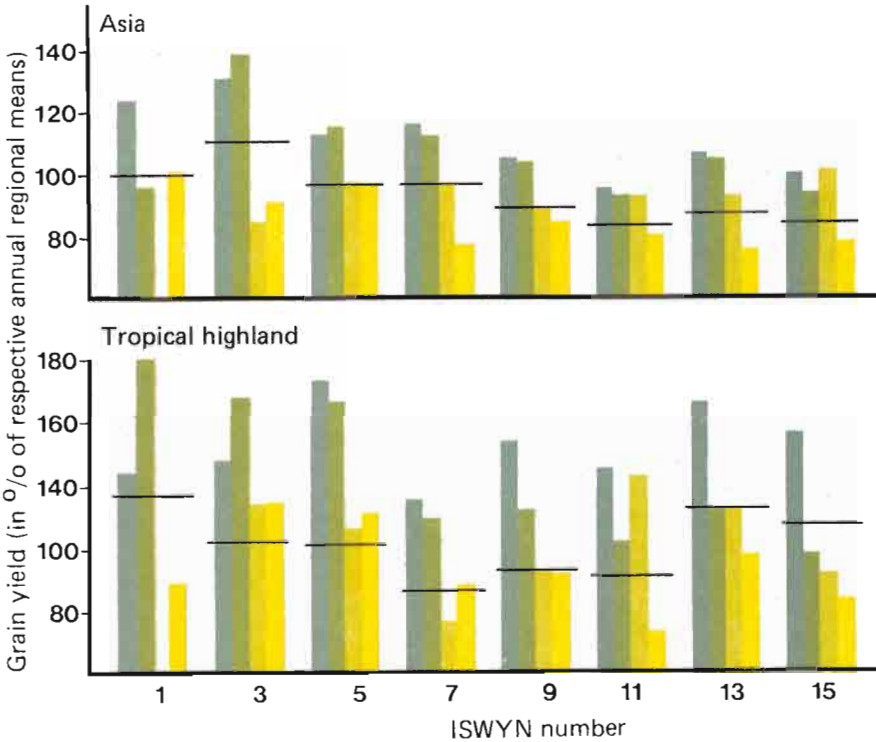
a regional basis and for groupings of similar environments. Stated somewhat differently, HYVs have at least the same yield stability as LDVs, but on a higher yield plateau.

However, in some special cases, using the sum of squared deviations from the regression line to characterize yield stability can be misleading. Returning for a moment to the varieties Nacozari 76 and Veery “S” (Figures 2 and 3), both are high yielders, and both fulfill the requirements for high yield potential and high input responsiveness. Nacozari 76 has a high yield stability, expressed as the sum of squared deviations from the regression line (ranked number 1 of 49 entries); Veery “S”, on the other hand, has a low yield stability when expressed as the sum of squared deviations, but it significantly out-yielded all other entries across all locations.

In Figure 3, the solid points indicate environments where there was either a high incidence of major diseases and/or specific requirements for adaptation. Note that three of these points lie far above the regression line for Veery “S” (the solid line), indicating the superior performance of the genotype at those specific sites. These large deviations distort the results, causing a high sum of squared deviations from the regression line, which infers a low yield stability. If these points are omitted from the analysis, Veery “S” also has high yield stability.

**Performance on a regional level**—A comparison was made between the four germplasm groups on a regional basis and on the basis of groups of specific environments. This comparison highlights the influence of the site-specific adaptation of the locally developed cultivars in groups III and IV.

The ecologically different regions of Asia and the tropical highlands are compared in Figure 4. The tropical highlands region includes environments above 2000 meters elevation in Africa, and in Central and South America. The wheat-producing areas in the tropical highlands are disease “hot spots,”



**Figure 4. Relative yield performance of the respective highest yielding genotypes (variety) of Group I, II, III, and IV in the Asian and Tropical Highland regions (— LSD at the .05 level as distance from the respective topyielder). (Pfeiffer, 1984)**

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making diseases one of the primary determinants of yield (other key production constraints include extreme temperatures and variable availability of moisture, ranging from an excess of water to drought).

Figure 4 shows the relative yield performance of 8 of the 15 ISWYNs (every other year). The data indicate the superiority of the respective best group I or group II entries, both across years and regions. Three general trends are obvious for the Asian region: first, group I entries in early ISWYNs out-yielded all other groups by far; second, in ISWYNs 5 through 9 a clear improvement is seen in the group II genotypes; and third, in later ISWYNs a clear trend can be seen toward the greater success of locally developed (group III) materials.

It should be mentioned that the decrease in the differences in yields on the relative (%) scale shown in Figure 4 is a result of increasing mean yields, i.e., the differences in absolute terms remained constant. Furthermore, some of the group III entries are of CIMMYT origins exclusively. For example, from the 15<sup>th</sup> ISWYN the best performing group III variety in Asia was Shasta, which is a cross between INIA 66 and Anza, both of which originated from CIMMYT.

A different pattern in the progress toward wheat improvement for the tropical highlands can be observed. In the early ISWYNs, materials selected for stripe rust resistance (from Colombia and Ecuador) showed the best performance in this region. Beginning with the 4<sup>th</sup> ISWYN (not shown), group I entries with excellent stripe rust resistance were available (e.g., Tobari 66), but these varieties did not respond well to improvements in fertility and gave relatively low yields in high-yielding environments. Over time, this limitation was eliminated by incorporating better responsiveness in materials resistant to stripe rust; these improved lines were available in subsequent cycles.

At the same time, emphasis was given to introducing better resistance to *Septoria* spp., a limiting disease in the tropical highlands. Varieties like Pavon 76, which combine the needed disease resistance with high yield potential and high input responsiveness, were the result of this breeding effort. These varieties still give very good performance across a global set of environments, as well as in specific areas.



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Finally, a new performance level was reached in the 15<sup>th</sup> ISWYN with genotypes stemming from spring x winter crosses. As noted earlier, Veery "S" (which carries the 1B/1R translocation) significantly out-yielded all other entries across all locations included in the 15<sup>th</sup> ISWYN. In the tropical highlands, it was the best performer by far; it also was the top-yielding line in the South American lowlands, the irrigated areas of northwest Mexico and the southern USA and also under rainfed conditions in the northern USA and Canada. In the Middle East region, Veery "S" yielded slightly lower than the top yielder, and in the Asian region its yield

was not significantly different from the top performer. The outstanding performance of the Veery lines indicated by this analysis has since been verified in ISWYNs 16 through 20.

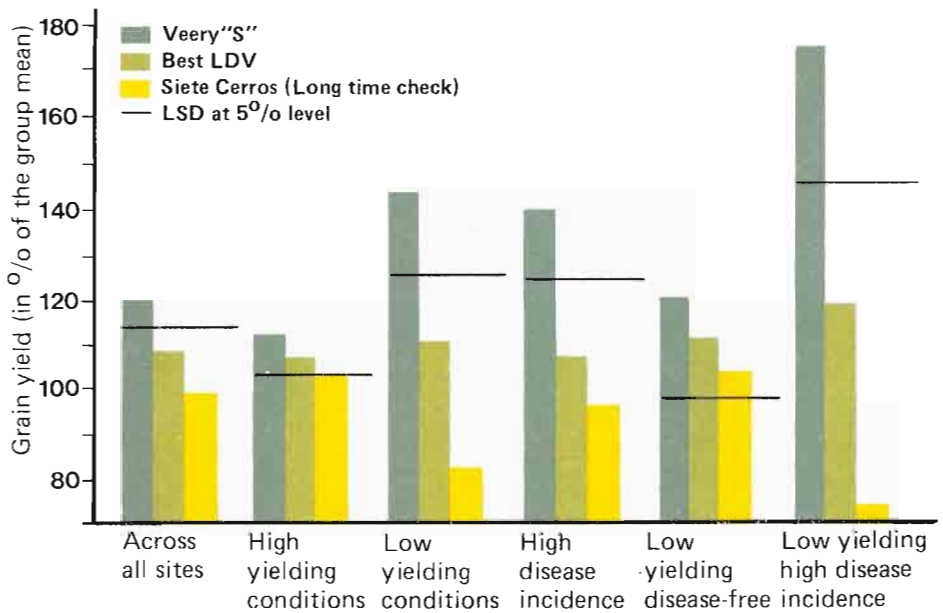
**Performance in different groups of environments**—A final illustration of the progress achieved is given in Figure 5. Groups of environments were formed using such criteria as their mean yield level and according to various production constraints, such as heavy incidence of disease. These groups can be further divided into subgroups, e.g., low-yielding environments having a high incidence of disease or low-yielding disease-free environments.



Veery "S" (Kavkaz—Buho x Kalyansona—Bluebird), a spring x winter wheat carrying the 1B/1R translocation, performs especially well in environments characterized by a high incidence of disease.

Figure 5 shows the relative performance in the 15<sup>th</sup> ISWYN of the CIMMYT line Veery "S", the best respective LDV and the long-time check variety Siete Cerros, a CIMMYT-developed cultivar included in the 1<sup>st</sup> to the 15<sup>th</sup> ISWYN. The LSD at the 5% level from the top yielder is shown by the solid lines. The yield advantage of the new varieties compared to the standard check and the LDV is

expressed in the significantly higher yields across the total of 76 environments. While a decisive advantage was not achieved in the high-yielding environments, an increase in the yield potential of the recently bred cultivars is obvious and proved to be statistically significant in individual high-yielding environments, such as northwest Mexico. The superiority of the new varieties was not as



**Figure 5. Relative grain yield of the CIMMYT variety Veery "S", the best locally developed variety (LDV) and the long time check variety Siete Cerros in eight different environmental groupings for the 15<sup>th</sup> ISWYN (Braun and Pfeiffer, 1982)**

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evident in the low-yielding, disease-free environments. However, yields under these conditions have improved by about the same relative amount (the same proportion) as compared to yields in high-yielding environments.

The reason for the outstanding yields obtained in environments with disease stress can often be found in the actual good yield potential of such sites when disease resistant varieties are grown. In contrast to the "real" low-yielding environments (e.g., drought environments), some of the disease environments are fertile enough to permit very good yields. In such cases, the disease resistance of a variety is the most important factor enabling it to profit from additional inputs, such as water and nutrients. A variety cannot produce yields above a certain limit associated with the absolute amount of the yield-determining input factors. Therefore, from the biological point of view, it is not possible for one variety to show much better absolute yields at the lower end of the environmental range if the yields are limited by the availability of inputs. Although differences between varieties in low input environments could be detected, these minor differences might be caused by a more efficient uptake of nutrients.

Finally, the data show that individual varietal attributes alone, like disease resistance, are not sufficient to make a cultivar outstanding. The complex character called "grain yield" is a function of a large number of environmental factors, all of which correspond to specific genes. The breeders' task is to incorporate and pyramid (when necessary) these genetic components to produce "true" high-yielding cultivars of the Veery "S" caliber.

### **Conclusions**

Four basic conclusions can be drawn from the analysis presented here:

- HYVs are at least as stable as LDVs under all environmental conditions (but on a higher yield plateau);
- HYVs are at least as input-efficient as LDVs (and generally more so) under all environmental conditions;
- HYVs are significantly more responsive than LDVs to improving production conditions; and
- "True" HYVs (the type produced following the CIMMYT breeding strategy) combine all three of the above characteristics.

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## Industrial Quality of Hexaploid Triticale

One of the main objectives of the CIMMYT triticale program is to produce hexaploid triticales that can be grown in areas of the world where wheat performs poorly, such as in the acid soils regions of Brazil. These triticales are intended for use both as feed grains and as food for direct human consumption.

As a food grain, triticale can be used to produce either wheat- or rye-type breads and other products. The flour used to produce these products must meet certain quality standards, which vary with the product being produced. Thus, the triticale program gives careful attention to screening its advanced germplasm for acceptable quality traits, and to producing a range of triticales possessing the quality characteristics necessary for various products.

Evaluation of the milling and baking quality of triticale was initiated at CIMMYT in 1972. At that time, even the best germplasm in the program had badly shrivelled grain.

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Such quality parameters as flour yield, alpha-amylase activity, dough strength<sup>1</sup> and bread loaf volume were deficient in the lines tested, when compared to bread wheats.

While most of the more recent triticales developed at CIMMYT meet the quality requirements for such products as cookies, tortillas and cakes (for which low flour protein and weak and extensible doughs are needed), only a few advanced lines combine the quality traits necessary for making acceptable raised breads. Because of this deficiency, intensive efforts are underway to increase the proportion of CIMMYT triticales combining the quality characteristics needed for making bread.

Until recently, quality data was used only sporadically to help select triticales progenitors. As improvements in grain plumpness and test weights were achieved, and as triticales moved closer to the threshold of commercial production, quality parameters became increasingly important for selection purposes. Giving higher

priority to the milling and baking quality of advanced materials soon began to pay off. The progress achieved is indicated in Table 3, which shows that the proportion of advanced triticales lines having satisfactory values for flour yield, alpha-amylase activity (as indicated by the Hagberg falling number<sup>2</sup>), and bread loaf volume is considerably larger in the Sixteenth International Triticale Screening Nursery (16<sup>th</sup> ITSN, to be distributed in 1985) than it was in the 10<sup>th</sup> ITSN (1977). The increase in triticales flour yield has resulted mainly from the significant improvements in grain plumpness and test weights achieved by breeders.

In addition to the progress toward improving seed quality in general, specific breeding research has been carried out to improve individually the grain compositional characteristics affecting the industrial quality of triticales. Lines with outstanding values for at least one quality parameter are used extensively as progenitors to develop new triticales with improved quality characteristics.

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<sup>1</sup> The term "dough strength" refers to the viscoelastic properties of a flour-water dough or suspension; it is measured as the response to forces applied during either a physical process (e.g., mixing of the dough during bread making), or during a chemical evaluation (e.g., the swelling capacity of the hydrated gluten protein in the flour-lactic acid suspension used in a sedimentation test).

<sup>2</sup> The Hagberg falling number test involves measuring the decrease in viscosity of a heated flour-water slurry. Decreases in viscosity are due mainly to the activity of alpha-amylase in the samples; low falling numbers correspond to higher levels of alpha-amylase activity.

### Research Methodology

The major quality measurements taken by the CIMMYT milling and baking laboratory are flour yield, alpha-amylase activity (with the falling number test), dough strength (with the Zeleny sedimentation test), gluten content and bread loaf volume.

Triticale flour yields are determined by milling the grain in a Buhler mill. Before milling, grain samples are tempered to a moisture level of 12.5 to 15.5%, depending on the hardness of the grain. The flour so obtained has an ash content below 0.55%.

Dough strength is primarily controlled by both the inherent viscoelastic properties of the gluten (the water-insoluble endosperm protein) and the amount of gluten in the flour. With the Zeleny

sedimentation test, the expansion and hydration capacity of the gluten protein in a flour/lactic acid suspension is tested. Flour samples with good dough strength produce a more expanded sediment than weak-dough flours. Gluten content is estimated by first washing a flour dough sample under a continuous stream of water to separate the starch and all the water-soluble material from the insoluble gluten protein. The remaining gluten is then heat-dried and weighed to determine the gluten content.

The high alpha-amylase activity that generally characterizes triticale flour negatively affects the bread-making quality of triticale doughs because the enzyme excessively hydrolyzes starch during the bread-making process. This negative effect can be decreased significantly by reducing the

**Table 3. Proportion (O/o) of lines in two ITSN<sup>a</sup> populations having satisfactory selected quality characteristics**

<b>Triticale population</b>	<b>Flour yield (≥68<sup>O</sup>/o)</b>	<b>Falling number (≥ 250 sec)</b>	<b>Bread loaf volume<sup>b</sup> (≥ 700cc)</b>
10 <sup>th</sup> ITSN (1977-78)	18.5	9.2	19.8
16 <sup>th</sup> ITSN (1983-84)	54.1	22.9	40.7

<sup>a</sup> International Triticale Screening Nursery

<sup>b</sup> 100g flour baking formula

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fermentation time during bread making. Thus, the CIMMYT lab uses a short fermentation time when testing the bread-making quality of triticale flours.

Intense selection pressure for milling and baking quality characteristics is not applied to segregating materials. Rather, attention is focused on advanced lines having good agronomic traits. These are the lines included in the International Triticale Screening Nursery (ITSN), International Triticale Yield Nursery (ITYN), and the Crossing Block (CB) populations. Those lines showing outstanding values for one or more of the quality characteristics tested are then crossed with other triticales, either to improve a particular characteristic or to produce new triticales combining good agronomic type and acceptable milling and baking quality.

### **Research Results**

During 1984, selected lines from the 16<sup>th</sup> ITSN (grown in the Yaqui Valley, Sonora, Mexico) were evaluated for their milling and baking quality. Results indicate that a wide range in flour yield, alpha-amylase activity, dough strength and bread-making quality exist among the 16<sup>th</sup> ITSN entries.

Many lines have acceptable values for at least one of the quality characteristics tested but, more importantly, some lines have acceptable values for all the parameters tested. The best of these outstanding triticales and their quality data are shown in Table 4.

**Flour yields**—The flour yields of the triticales listed in Table 4 were lower than those of the bread wheat checks, but most of them were within 3-4 percentage points of the bread wheats. As the grain plumpness and test weights of these lines continue to improve, flour yields can be expected to increase.

**Alpha-amylase activity**—The falling number values of these lines indicate satisfactory levels of alpha-amylase activity. Moreover, five lines (entries 136, 139, 155, 158, 164) have the large falling number values typically found in wheat but not in triticale. Thus, a few triticales are now available that produce flour with quality characteristics comparable to that produced by sound, unsprouted wheat.

**Flour and gluten protein content**—Most of the triticales in Table 4 have higher flour protein content than the two wheat checks. These triticales also were

high (but lower than the wheat checks) in gluten-type protein (less than 55% of the flour protein produced by most of the presently available triticales is in the form of gluten).

A major factor controlling dough strength and bread-making quality is the gluten content of the flour, which is lower in triticale than in wheat. Significant improvements in triticale dough strength and bread-making quality primarily depend on transferring the viscoelastic properties of bread wheat gluten to the gluten of triticale. This is being done mainly through interspecific crosses between selected hexaploid triticales and certain bread wheats.

**Sedimentation values**—The high flour protein content, particularly of the gluten-type, contributed significantly to the large sedimentation values produced by these lines. Since the average sedimentation value for the entries in the 16<sup>th</sup> ITSN is 21 cc, the lines shown in Table 4 can be considered as outstanding in this respect, especially the lines Fawn''S''—ABN''S'' and PTR''S''—GZL''S'' x PND''S''—ABN''S'', which had sedimentation values of 38 and 48 cc, respectively.

**Bread loaf volume**—The improved dough strength of the lines in Table 4 was directly reflected in their

**Table 4. Triticale lines of the 16<sup>th</sup> ITSN population that combine good quality characteristics**

Entry number	Name or cross	Flour yield (°/o)	Falling number (sec)		Flour protein (°/o) <sup>a</sup>	Gluten protein in flour protein (°/o)	Sedimentation (cc)	Bread loaf volume (cc)
			grain	flour				
134	Fawn''S''—ABN''S''	69.0	228	456	11.3	60.4	38	860
135	Caborca 79—PND''S''	67.8	129	277	11.7	61.4	33	795
136	PTR''S''—GZL''S'' x PND''S''—ABN''S''	60.4	371	730	12.5	56.8	48	825
139	CML''S''—KAL x Lobo/PTR''S''—RM''S''	69.4	302	595	11.4	59.1	35	865
147	BVA—PND''S''	69.0	204	218	11.1	51.1	35	840
148	BSN—PTR''S''	67.1	292	402	11.0	58.9	27	830
149	PND''S''—ABN''S'' IA(2)	67.6	142	302	10.9	61.0	32	855
155	Fawn''S''—ANB''S''	66.9	385	612	11.3	57.3	38	845
156	CML''S''—Pato x LMG''S''	66.8	323	446	11.0	58.1	30	830
158	PTR''S''—M <sub>2</sub> A <sup>2</sup>	67.9	426	800	10.6	55.2	34	885
163	PTR''S'' x M <sub>2</sub> A—FS 1377/IA x CIN''S''—FS 658	66.6	256	454	11.3	62.0	32	840
164	BSN''S''—PTR''S''	67.3	351	516	11.6	63.5	33	825
171	EDA''S'' x M <sub>2</sub> A—ZA75	68.2	289	320	10.3	59.4	30	865
244	PND''S''—LNC''S'' x TGE''S''	66.8	206	270	10.7	57.2	25	810
Wheat checks:								
69	Seri 82	72.6	482	900	10.3	73.2	32	825
72	Genaro 81	71.6	680	827	10.9	73.2	33	790

<sup>a</sup> at 14°/o mb



large bread loaf volumes. These triticales should therefore be suitable for making most of the various breads consumed around the world.

**“Complete” vs. “substituted” triticales**—There are two major types of hexaploid triticales:

- “Complete” triticales, which retain all the chromosomes (AABBRR) from their wheat and rye parents, and
- “Substituted” triticales in which 1 or 2 D-genome chromosomes from wheat replace the homeologous rye chromosomes.

Improvements in dough strength and bread-making quality are believed possible with the substituted types due to the contribution of the D-genome chromosome(s) to the viscoelastic properties necessary for the production of acceptable bread. The absence of D-genome chromosomes in the background of complete hexaploid triticales is

responsible for the lack of viscoelastic gluten in this type of triticale. However, among the complete triticales included in the 16<sup>th</sup> ITSN, some lines showed improved dough strength and bread-making quality (Table 5). This improvement could be due to translocations between chromosomes of the D-genome (A- and/or B-genomes also) and rye chromosomes in the triticale x wheat crosses, or to crossovers between homeologous chromosomes in the interspecific crosses. In any event, the improvement of the dough strength and bread-making quality of complete triticales may eventually contribute to their use in those areas where they perform better than the substituted types.

**Pre-harvest sprouting**—It should be pointed out that the satisfactory quality of some triticale lines grown in well-managed, irrigated land (such as that of the Yaqui Valley) often becomes unacceptable when these lines are grown at other locations. In particular, when

**Table 5. Quality data for complete triticales having improved dough strength and bread-making potential, 16<sup>th</sup> ITSN**

Entry number	Name or cross	Flour yield (°/o)	Falling number (sec)		Flour protein (°/o) <sup>a</sup>	Gluten protein in flour (°/o)	Sedimentation (cc)	Bread loaf volume (cc)
			grain	flour				
64	B 5644-777-1Y-1Y-0M	70.6	147	205	9.5	50.4	29	775
65	B 5644-778-2Y-1Y-0M	69.2	118	240	9.3	52.5	30	805
66	B 5644-778-2Y-3Y-0M	68.9	165	294	9.5	48.6	31	790

<sup>a</sup> at 14<sup>o</sup>/o mb

triticale is grown in areas having moist environmental conditions at harvest, preharvest sprouting tends to be a problem.

Flour from sprouted grain samples has high levels of enzymatic (amylolytic) activity, which results in a deterioration of the structure of fermenting doughs during the bread-making process. Pan-type breads obtained from such flours have low loaf volumes, unacceptably sticky crumb and dark crusts (Figure 6). The quality of other baked products also can be affected by the high enzymatic activity of sprouted grain. Thus, preharvest sprouting limits the production potential of most triticales in those regions of

Mexico, Brazil, Canada, Northern Europe and other areas of the world where moist conditions usually prevail during harvest.

Ideal conditions for screening triticale against pre-harvest sprouting occurred during the summer of 1984. Unusually heavy precipitation fell during both the late maturation stage and during harvest at three experimental sites in Mexico: Huamantla, El Batán and Toluca. Toluca received the most rainfall, and El Batán the least. Seventy-one entries of the 16<sup>th</sup> ITSN were evaluated for alpha-amylase activity using the Hagberg falling number test. Results showed that most of the triticales, as well as the wheat check variety (Genaro

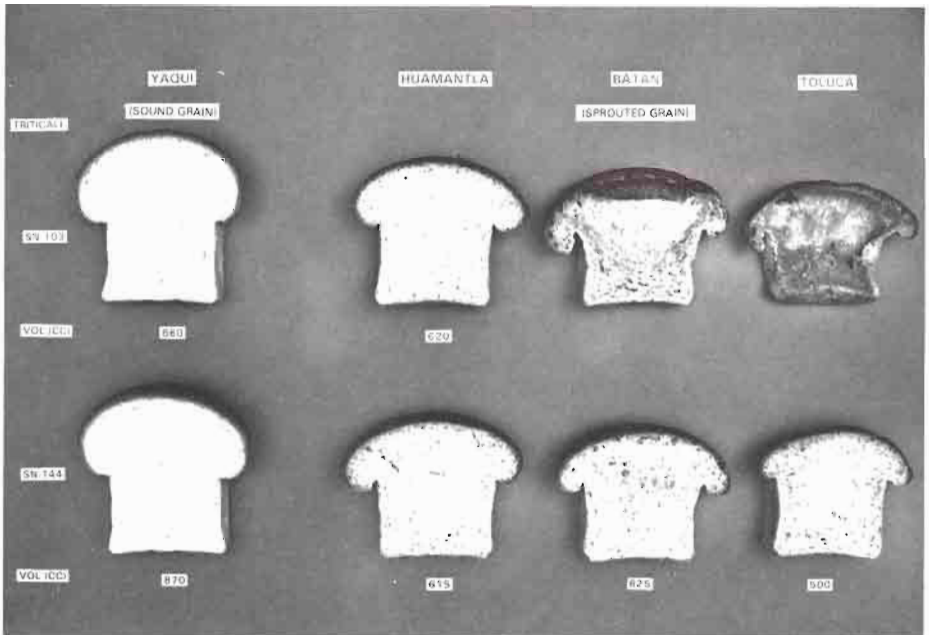


Figure 6, Breads made with flours from two triticales (SN-103, 144) grown at four different locations

81) were very susceptible to preharvest-sprouting under the moist conditions at the Toluca station. While only six lines showed some degree of sprouting resistance at all three testing locations (Table 6), slow progress is evident: all but one of the lines in the 12<sup>th</sup> ITSN, when grown at the Toluca site, had unacceptably high levels of alpha-amylase activity.

### Conclusions

Evaluation of the 1984 triticale crop shows that significant progress has been made toward improving the milling and baking quality of the grain. While much remains to be done, primarily in improving flour yields and resistance to pre-harvest sprouting, genetic sources for improving the quality of triticale are available in the germplasm base. The current trend toward improving the milling and baking quality of hexaploid triticales should therefore continue

at least at its present rate, and possibly accelerate as greater attention is given to these selection criteria.

### Balanced Fertilization: A Key to Increasing Wheat Yields in Argentina

Argentina has long played a significant role in the world cereal market. As the global demand for cereals (especially wheat) has increased, Argentina has responded by increasing production and exports. The growth in Argentinian cereal production has been achieved both through increases in the area sown and through greater yields per hectare. Since 1974, wheat production increases have been fueled by the widespread adoption and use of higher yielding germplasm.

**Table 6. Falling numbers (seconds) of triticale lines from the 16<sup>th</sup> ITSN having some degree of sprouting resistance at various testing locations**

Entry number	Name or cross	Location							
		Huamantla		Batan		Toluca		Yaqui	
		grain	flour	grain	flour	grain	flour	grain	flour
10	MUS"S"-JLO"S"	226	192	355	358	172	256	392	310
63	Pipit"S"-1158.57 x UC90 (MUS"S"-MA/Drira - IA x BGL"S")	133	166	155	194	182	173	225	295
66	B 5644-778-2Y-3Y-0M	132	186	300	286	149	230	265	294
73	Pika"S"	222	254	119	221	152	216	358	458
157	PTR"S"-YO"R" x PND"S"	256	228	420	235	143	144	274	314
158	PRT"S"-M <sub>2</sub> A <sup>2</sup>	419	262	131	109	207	207	426	800
72	Genaro 81 (Wheat check)	-	-	372	372	61	61	680	827

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It is remarkable that, historically, fertilizer has not played a significant role in raising Argentina's wheat production, while fertilizer has been a key ingredient in the worldwide success of the "Green Revolution." Two reasons for Argentina's low application of fertilizer are:

- A lack of fertilizer response data for the newer, high-yielding cultivars, and
- Input-output (fertilizer-grain) price relationships that were not conducive to the use of fertilizer.

In 1979, the Instituto Nacional de Tecnología Agropecuaria (INTA) at Pergamino and at Marcos Juárez,

Argentina, began a network of nitrogen (N)/phosphorus ( $P_2O_5$ ) trials using new fertilizer-responsive wheat cultivars. CIMMYT's Southern Cone agronomy program has participated actively in this program. INTA Balcarce has also conducted a network of fertilizer trials. To date, approximately two hundred trials have been placed in farmers fields.

This cooperative research effort has achieved the following:

- The establishment of response data for high-yielding cultivars to both nitrogen and phosphorus;
- The establishment and verification of a higher yield



An extensive network of N/ $P_2O_5$  trials was initiated in 1979 by INTA/Pergamino and INTA/Marcos Juárez to obtain information on the responsiveness of new wheat cultivars to various applications of fertilizer.

potential for wheat grown in the Pampa Húmeda, when grown using properly balanced fertilization;

- The accurate correlation and calibration of soil test data with wheat yield responses; and
- The use of these technical data to help support a government-sponsored fertilizer program for wheat, initiated in 1984.

### Research Methodology

In 1980, five nitrogen treatments were used in the experiments (0, 30, 60, 90 and 120 kg/ha), along with two additional treatments of 0-60 and 120-60 kg of N and P<sub>2</sub>O<sub>5</sub>, respectively. During the four years from 1981 to 1984, an incomplete factorial experimental design was implemented. The

levels of N applied were 0, 30, 60, 90 and 120 kg/ha, while those of P<sub>2</sub>O<sub>5</sub> were 0, 20, 40, 60 and 80 kg/ha. Phosphorus was applied as triple superphosphate and nitrogen in the form of urea. Both nutrients were broadcast before sowing and then incorporated with a disk harrow.

Plots were laid out using a randomized complete block design, with three replications in 1980 and two replications from 1981 onward. The plots were seven meters wide and either 20 or 30 meters long, depending on the space available at each site. Sites were characterized by certain soil, climatic and management parameters, and the average values and the variability of these parameters are shown in Table 7.

**Table 7. The average value, range and standard deviation of various site parameters (N = 65)**

Parameter	Average value	Range	SD
pH	5.9	5.2 – 6.2	0.2
Organic matter (‰)	3.13	2.0 – 4.7	0.61
Total N (‰)	0.139	0.082 – 0.196	0.027
NO <sub>3</sub> <sup>-</sup> (0-20 cm) (ppm)	52	15 – 136	25.4
Soil P Bray 1 (ppm)	12.4	3.4 – 36.0	6.8
Depth of A	27.9	21 – 24	3.3
Available H <sub>2</sub> O to 1.5 m (mm)	221	107 – 357	52
Total rainfall (mm)	250	111 – 373	67
Rainfall, sowing to tillering (mm)	55	0 – 206	48
Rainfall, tillering to flowering (mm)	102	4 – 239	51
Rainfall, flowering to maturity (mm)	93	16 – 208	47
Years of continuous cropping	11.9	0 – 50	8.8
Length of fallow	60	10 – 270	44

## Research Results

Wheat response data for 1982 (considered a wet year) and 1983 (a dry year) are shown in Tables 8 and 9, respectively. These data show that spectacular responses to fertilizer occur, even in a dry year like 1983. The response to N when applied alone is moderate, and is highly dependent on moisture availability, as is apparent in the 1982 (wet year) data. The response to phosphorus when applied alone is small, but there is a very strong N x P interaction and a properly balanced application of these two elements is extremely efficient. For example, an application of 30 kg of N and 20 kg of  $P_2O_5$  resulted in an increase of 1000 kg/ha in 1982, or an efficiency of 20 kg of grain per kilogram of nutrient applied. The corresponding figures for 1983

were 670 kg/ha and 13.4 kg of grain per kilogram of nutrient applied.

Tables 8 and 9 demonstrate not only the strong interaction between nitrogen and phosphorus, but also that high yield levels are obtainable. In 1982, a year with adequate moisture, the average yield obtained at the maximum fertilizer application rate (120-80) was 4790 kg/ha. This indicates a new potential for wheat yields in the Pampa Húmeda, which can only be obtained with a proper balance of nitrogen and phosphorus.

**Correlation and calibration of soils data**—Two important conclusions regarding the use of soils data can be drawn from this research:

- 1) In the case of wheat, soil nitrate analyses at sowing time do not provide an adequate basis for

Table 8. Average wheat yields (kg/ha) at varying levels of N and  $P_2O_5$  (kg/ha) in the Pampa Húmeda, 1982 (n = 18). Source: INTA, Pergamino

$P_2O_5$	0	20	40	60	80
N					
0	2960		3080		3070
30		3960		4270	
60	3850		4410		4528
90		4530		4760	
120	4140		4710		4790

making recommendations for nitrogen fertilization. Rather, these recommendations should be based on such agronomic data as the yield potential of the area, the number of years of continuous cropping, the previous crop grown, the length of the fallow period, and the amount of stored moisture. Integrating all of these factors into sound nitrogen application recommendations requires a great deal of field experience.

2) Soil analyses are useful in predicting responses to phosphorus, as indicated by Figure 7 in which the Bray 1 phosphorus test is correlated with yield responses. As a result of this correlation, soils are now grouped into various classes

according to the availability of phosphorus:

- More than 15 ppm of phosphorus — adequate,
- 7-15 ppm of phosphorus — deficient, and
- Less than 7 ppm phosphorus — very deficient.

**Fertilizer recommendations**—Based on this research and on the subsequent correlation and calibration of data from soils tests, recommendations for fertilizer use were formulated and then field tested by INTA in 1983 on sixteen different sites (Table 10). The recommendations were developed using the then prevailing input-output price ratio of 9:1, the price of one unit of nitrogen (Pn) to the price of one kilogram of wheat

Table 9. Average wheat yields (kg/ha) at varying levels of N and P<sub>2</sub>O<sub>5</sub> (kg/ha) in the Pampa Húmeda, 1983 (n = 18). Source: INTA, Pergamino

P <sub>2</sub> O <sub>5</sub>	0	20	40	60	80
N					
0	2150		2410		2380
30		2820		3270	
60	2660		3250		3550
90		3310		3780	
120	2930		3640		4060

(Pw). The data in Table 10 indicate that a wide range of conditions was sampled and that the parameters influencing response varied considerably. These parameters included the soil P test, number of years of continuous cropping, the preceding crop, the amount of rainfall, and the variety and check yields.

Even at a Pn:Pw of 9:1, during a dry year and under extremely variable conditions, the recommended applications of fertilizer proved to be efficient. In all but two sites, the response efficiency was 9 or higher, and the average response efficiency was about 16:1.

Data from the kind of research presented here offers policy makers a clearer sense of the advantages of bringing agricultural input prices into closer alignment with prevailing world levels. In 1984, the new Argentine government took a series of steps to encourage the application of fertilizer on wheat. The main incentive was to keep the Pn:Pw relationship at 5:1, and fertilizer was paid for in grain at harvest. About 100,000 tons of urea were distributed under this program, with dramatic implications for production. The government expanded this program in early 1985, which should result in rising average yields per hectare (and therefore increases in total production) in the years ahead.

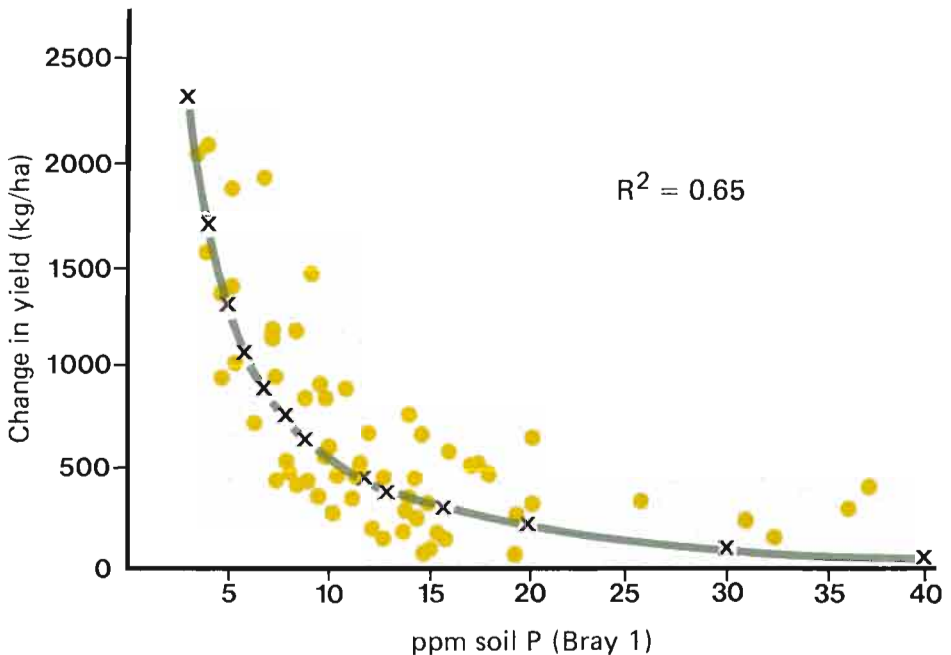


Figure 7. Relation between soil P (Bray 1) and response to applied P



**Table 10. Results of demonstrations based on fertilizer recommendations, Pergamino, 1983**

Site	P (ppm)	N <sub>03</sub> (ppm)	Optimum economic dose (OED)		Years of continuous cropping	Preceding crop	Rainfall (mm)	Variety	Check yield (kg/ha)	OED yield (kg/ha)	Difference OED check kg nutrient)	Response efficiency (kg grain/kg check kg nutrient)
			N	P <sub>2</sub> O <sub>5</sub>								
Bragado (La Paz)	30.5	22	32	0	2	Wheat	270	1850	2600	750	23.4	
Bragado (Don Adolfo)	11.3	22	38	16	6	Sunflower	270	1790	2750	960	17.8	
Bragado (Macías)	5.1	22	48	40	+10	Wheat	270	1080	2540	1460	16.6	
9 de Julio (Obligado)	10.2	22	35	18	—	Triticale	141	1470	2400	930	17.5	
9 de Julio (Del Fabro)	8.0	24	44	23	+10	Sunflower	244	2340	4190	1850	27.6	
9 de Julio (Del Fabro)	8.0	24	44	23	+10	Sunflower	244	3640	3830	190	2.8	
9 de Julio (La Norumbega)	15.7	20	23	0	6	Soybeans	244	3430	4150	720	31.3	
Venado Tuerto (La Chispita)	13.5	33	40	0	+10	Soybeans	258	2250	2800	550	13.8	
Chivilcoy (Castro)	5.5	22	11	30	—	Soybeans	—	2050	2700	650	15.9	
9 de Julio (Castro)	7.1	24	40	30	6	Maize	244	2980	3910	930	13.3	
9 de Julio (Carrilla)	10.5	24	23	18	5	Wheat	244	2660	2840	180	4.4	
Bragado (Quarleri)	7.7	24	48	28	9	Maize	270	1860	3030	1170	15.4	
Pergamino (Guernico)	12.0	33	30	0	+10	Soybeans	324	1010	1280	270	9.0	
Pergamino (Basualdo)	19.0	28	25	0	15	Soybeans	324	1800	2530	730	29.2	
Pergamino (M. Ocampo)	9.6	25	30	20	12	Soybeans	324	1330	1780	450	9.0	
Chacabuco (Zubiri)	8.0	60	18	46	—	Soybeans	388	2150	3220	1070	16.7	
								x	2110	2990	880	15.7

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## Improving the Disease Resistance of Barley

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From its inception in 1972, the CIMMYT barley improvement program made significant progress toward the development of advanced lines having good plant type, stiff straw and high yield potential (over 6 t/ha). In particular, the development of high-yielding, early maturing lines (90-95 days) now offers farmers in certain locations (such as the Yaqui and Mayo Valleys of northwest Mexico) the possibility of fitting barley into their crop rotations, utilizing land that might otherwise lie idle between crops.<sup>1</sup>

The improved barley materials developed by CIMMYT during the last 13 years have contributed significantly to increased production in a number of locations, especially those in which diseases are not an important

production constraint. In environments that favor disease development, however, the improved materials fared less well. For this reason, in 1981 the CIMMYT program began giving much greater emphasis to incorporating resistance to the major diseases commonly found in the important barley-producing regions of the world. In doing so, special care is being taken to maintain the desirable agronomic traits that characterize CIMMYT's advanced lines.

In July, 1984, the world mandate for barley improvement shifted from CIMMYT to the International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria. Barley breeding will continue at CIMMYT under the auspices of ICARDA. The emphasis of the Mexico-based breeding program, however, will continue to be on incorporating improved disease resistance into barley germplasm having good agronomic traits (with special attention to the disease problems affecting barley production in Latin America). The progress made to date in this effort forms the basis for this highlight report.

### Research Methodology

The major diseases affecting barley include leaf rust (*Puccinia hordei*), scald (*Rhynchosporium secalis*), stripe rust (*P. striiformis* f.sp. *hordei*), net blotch (*Helminthosporium teres*), barley yellow dwarf

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<sup>1</sup> Due to the rapid vegetative development of early barleys, tillering is reduced compared to full season genotypes and complete ground cover is rarely achieved. CIMMYT agronomists recently developed improved cultural practices for these early lines. It was found that, as the space between rows decreased, significant increases in yield were obtained. The highest yields were obtained with a 10 cm spacing, which resulted in a more than 25% increase in yield over the 20 cm row-spaced plots.

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(BYD), and fusarium head scab (*Fusarium* spp.). A step-wise approach to incorporating resistance to these diseases was adopted. First, a “template of resistance” to leaf rust and scald was built across the entire germplasm base. Materials carrying this template were tested for their yield potential during the 1984/85 winter cycle (see “Research Results”). Resistance to other important diseases is now being added to the germplasm base; resistance to BYD will be incorporated across the entire germplasm base, and resistance to other diseases will be added to

subsets of germplasm that are better adapted for specific barley-producing regions around the world.

Leaf rust and scald were chosen for building the initial template of disease resistance, primarily because of their importance in Mexico and South America. In addition, heavy selection pressure for resistance to leaf rust and scald can be brought to bear at the screening sites used by the program in Mexico. Severe artificial epidemics of leaf rust are created during the winter cycle at the CIANO Experiment Station in



Barley research at CIMMYT is now giving much greater emphasis to incorporating disease resistance into barley

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Northwest Mexico (located in the Yaqui Valley, near Ciudad Obregon). During the summer cycle, artificially induced epidemics of both scald and leaf rust are used to select for resistance at the El Batan and Toluca Experiment Stations in central Mexico. The severe disease pressure used in the selection process, combined with the advantage of having two cycles of plant breeding per year, resulted in a rapid transformation of the entire germplasm base in a remarkably short period of time.

**Leaf rust methodology**—The identification of lines or varieties resistant to leaf rust is not a new research effort, but work in this area has been considerably intensified in recent years. New barley entries from other breeding programs around the world and over 11,000 accessions of the USDA World Barley Collection have been screened for resistance over several crop cycles. The most resistant lines are being used in the crossing program, the objective being to widen the germplasm base.

All barley nurseries grown at the three main screening sites in Mexico are inoculated with leaf

rust. Several nighttime applications of rust spores mixed in talcum powder, plus an additional needle inoculation using an aqueous spore suspension, have consistently produced severe epidemics that have enabled a reliable selection of resistant plants.

Two sources of genetic resistance have been used to acquire the leaf rust resistance now present in the germplasm base:

- Major gene resistance (the Pa genes), and
- Minor gene resistance.

Major gene resistance is relatively easy to monitor (progeny are either resistant or susceptible). Surveys of barley leaf rust virulence in Mexico have detected the presence of *P. hordei* races 8, 19 and 30 (race 19 is predominant), and three of the major resistance genes (Pa, Pa4 and Pa5) are not effective against these races. The program has therefore incorporated other major genes into the germplasm base, such as Pa3 and Pa7, that confer resistance to the races present in both Mexico and South America. Other sources of resistance are being used in the program as well, though the genes conferring resistance are unknown at this time.

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The incorporation of minor gene resistance is more difficult to monitor than major gene resistance, but by repeatedly crossing parental material carrying this type of resistance, the minor genes eventually will be “pyramided” together. By combining both resistance mechanisms, it is expected that resistance to leaf rust will become more stable.

**Scald methodology**—The reactions of differential lines to scald in three different locations in central Mexico indicate significant changes in virulence (both between sites and at the same site from one year to the next), clearly demonstrating the need for a wide spectrum of resistant parental material. The resistance to scald now incorporated into the germplasm base comes from parental material carrying major genes for resistance. New sources of resistance from Ethiopia, California (USA) and Australia are currently being used in the crossing program.

Due to unfavorable environmental conditions, scald inoculations are not effective at the CIANO Experiment Station. However, three screening sites in central Mexico are used by the program, each having conditions favorable to the

development of severe scald epidemics (primarily the frequent late afternoon rains). Artificial inoculations are made at each location, using two techniques:

- Scald-infected straw saved from the previous crop is chopped into pieces and scattered between the rows at the tillering stage.
- An aqueous spore suspension is applied with ultra low-volume spray applicators (ULVAs) after the late afternoon rains. For this technique, spores can be obtained either from laboratory cultures, or by using the following procedure developed by Dr. L.J. Piening, Alberta, Canada:

- 1) Scald-infected leaves are placed in a plastic bag, wet paper tissues are added to supply humidity and the bag is sealed and stored for 24 hours at 15-20°C.

- 2) One liter of distilled water is then added to the bag after removing the paper tissues and the contents are shaken for a few seconds and decanted into a beaker.

Spore production with Piening's simple method is not high compared to laboratory cultures, but neither does it require sophisticated equipment. No attempt to quantify the spore concentration has been made because the resulting suspensions are repeatedly applied to the plots. The ULVA technique is efficient and is easy to use. In combination with the Piening method of spore production, the ULVA technique also enables the screening of germplasm against isolates, and possibly new races of scald, almost immediately.

### Research Results

Yield experiments conducted during the 1984/85 winter cycle with lines resistant to both leaf rust and scald gave a clear preliminary indication that a combination of high yield potential (over 8 t/ha) and resistance to these diseases has been achieved (Table 11).

The severity of the leaf rust and scald epidemics created during the last six crop cycles in Mexico resulted initially in a drastic reduction in the number of lines maintained in advanced

**Table 11. Highest yielding advanced barley lines having resistance to both leaf rust and scald, CIANO, 1984/1985**

	Yield (t/ha)	Leaf Rust*	Scald**
Gloria/Copal''S'' CMB81-295-30B-4Y-9M-3Y-0M	8.3	10MR***	R
Gloria/Copal''S'' CMB81-295-30B-4Y-20M-1Y-0M	8.1	10MR	R
Gloria/Come''S'' CMB81-294M-25Y-6B-2Y-0M	8.0	R	R
Gloria/Copal''S'' CMB81-295-30B-4Y-18M-1Y-0M	8.0	R	R
Gloria/Copal''S'' CMB81-295-30B-4Y-9M-1Y-0M	7.9	10R	R
Gloria/Copal''S'' CMB81-295-30B-1Y-2M-2Y-0M	7.9	5MR	R
Gloria/Copal''S'' CMB81-295-30B-4Y-1M-1Y-0M	7.8	10R	R
Gloria/Copal''S'' CMB81-295-30B-4Y-19M-1Y-0M	7.8	10R	R
Gloria/Come''S'' CMB81-294-4Y-1H-6Y-2M-1Y-0B	7.8	10R	R
Gloria/Come''S'' CMB81-294-17Y-1B-1Y-0M	7.6	10R	R

\* Modified-Cobb scale

\*\* R = Resistant

\*\*\* MR = Moderately Resistant

generations. A comparison of the number of F<sub>5</sub> lines in the program during subsequent growing cycles illustrates both the severity of the selection pressure applied and the progress made toward incorporation of disease resistance into good agronomic backgrounds (Figure 8). A large proportion of the material grown at El Batan in 1982, although high yielding and of good agronomic type, was discarded due to the program's shift in emphasis toward disease resistance. However, the large number of F<sub>5</sub> lines grown at CIANO in 1984-85 indicates the program's progress toward incorporating the leaf rust/scald template into material of superior agronomic background.

A small, on-going effort was begun in 1982 to identify and incorporate resistance to stripe rust, and the program currently has lines at the F<sub>3</sub> generation that possess resistance not only to stripe rust, but to leaf rust and scald as well. However, this resistance will not be incorporated across the entire germplasm base; rather, the focus of resistance breeding is on selected subsets of germplasm adapted to the environmental conditions of South American barley-growing regions.

Resistance to race 24 of *P. striiformis* is especially important to barley growers in South America. The disease first appeared in Colombia in 1976 and subsequently expanded throughout all the barley-growing areas in the South American Andes. Sources of resistance to race 24 have been identified in South America and in Europe, and the Mexico-based barley program is undergoing a massive infusion of germplasm from these areas. New varieties and advanced lines having resistance to stripe rust are rapidly being incorporated into the crossing program.

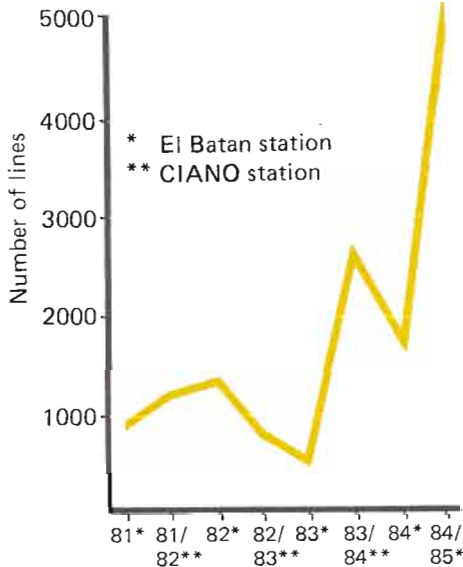


Figure 8. Number of F<sub>5</sub> barley lines in subsequent breeding cycles, El Batan 1981 to CIANO 1984-85

Screening and selection of stripe rust-resistant materials is done by various national programs in South America. Preliminary results indicate that a considerable number of resistant plants are being generated using three-way crosses, where two of the parents involved carry stripe rust resistance. Resistant plants identified and selected in Ecuador and Bolivia will be brought back to CIMMYT headquarters for planting in the greenhouse and for use in the breeding program (a single-seed descent breeding methodology is being implemented that reduces the generation time required to develop homozygous, advanced lines). Advanced lines developed in this

way will be sent back to the originating national programs for final yield testing under local conditions.

### Future Plans

With the leaf rust/scald template firmly established, the program is turning its attention to improving the stripe rust resistance of its South America-bound germplasm. This aspect of the program will take on greater importance as the geographic focus of the Mexico-based program shifts to Latin America.

Significant progress has been made in identifying lines resistant to BYD (Table 12). Unfortunately, most of these lines are susceptible to many

**Table 12. BYD-resistant barley lines being used as parents in the breeding program (0-9 scale)**

Cross and pedigree	New Zealand	Toluca	California USA	Quito Ecuador
Duchicela	2	3	5	4
PI 1382406	1	2	4	—
PI 1382411	1	2	5	—
Sutter	3	4	2	—
Sutter (2)—Numar	3	3	3	—
*Boy(2)—Surb(3) x CI 12225.2D	4	2	4	4
*CI2325—CI1222.5 x Boy(2)—Surb(3)	2	4	6	4
Boy—MCU 3048.1D x CI 1463.3D	3	6	5	6
*PI 14116.13D—CI12225 x CI12917.37D	2	3	3	6
*(CI2375—CI12225 x CAN—MCU 29/TIB) CI12225.23 D	1	3	3	5
*Row 906.73	3	3	3	5
*ESCII 7283—3E—7E—1E	6	2	4	4

\* Resistant to stripe rust



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of the other major diseases affecting barley (some combine BYD and stripe rust resistance). An extensive crossing program is being initiated that should eventually result in the incorporation of BYD resistance across the entire germplasm base. Thus, resistance to BYD will become the third tier of the disease-resistance template.

Net blotch (*Helminthosporium teres*) is worldwide in distribution, but can be particularly severe in the barley-growing regions of the Mexican high plateau. The barley

program maintains a block of resistant parental material and is now beginning to pyramid net blotch resistance onto the leaf rust/scald template in materials adapted to Mexico's production conditions. As with stripe rust, this resistance will not be spread across the germplasm base, but will be incorporated into selected subsets of materials. In the case of net blotch, inoculum production and plant selection techniques are similar to those used for scald.



### Introduction

The CIMMYT Economics Program concentrates most of its energies on issues related to technology generation. Its methodological approach rests on the conviction that, to be effective, an important part of the technology generation process must be done in the fields of representative farmers. CIMMYT's involvement with national program researchers in technology generation takes two forms: (1) collaborative research projects to demonstrate on-farm research procedures and (2) training and advisory services to develop national on-farm research program components within national research systems.

A second activity concentrates on developing procedures that can contribute to decision making on the allocation of research resources. The technique rests on an assessment of comparative advantage through analysis of the full costs of resources required for the production of alternative crops, in our case emphasizing maize and wheat. These procedures can make more precise the trade-offs among crops and the amounts by which research must increase productivity if a crop is to be deemed profitable by farmers and by the nation. Such information can help managers to decide among crops and regions in assigning research resources.

CIMMYT economists also provide data and analysis for decision making within CIMMYT. Research studies are under way on aspects of maize and wheat in the world economy. Reports are produced on a regular basis that assemble pertinent data related to maize and wheat production, prices, utilization and trade, and present this information in a readily digestible form for agricultural researchers, administrators or policy makers.

Included in this year's report are highlights of representative research activities in each of the Economics Program's major areas of concentration.

### Technology Generation

In cooperation with colleagues in national research institutions, CIMMYT has sought to develop procedures which help to focus agricultural research activities on the needs of representative farmers. The research methodology has three operational phases: (1) identifying farmer circumstances and assessing these for research opportunities, (2) ranking the potential research opportunities in terms of their probable payoffs, and (3) undertaking on-farm experimentation that focuses on high-priority research opportunities.

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The work of the Economics Program has been on the development of cost-effective procedures for all phases of this research process, but with special emphasis on the first two operational phases.

From the outset, Economics Program staff have worked with selected national programs in developing and demonstrating these on-farm research procedures. Training has evolved as an essential component in the institutionalization of this approach to technology generation. Training is being implemented in collaborating developing countries through in-country courses that are tailored to meet the needs of each particular country.

By 1984, more than a dozen collaborating national research institutions were well on their way towards integrating on-farm research procedures into the process of technology generation. The on-farm research activities in the Haitian national maize program are highlighted in this year's report.

### **On-Farm Research Methodologies at Work in Les Cayes, Haiti**

**Background**—In 1980, the Haitian Department of Agriculture invited CIMMYT to collaborate in the development of an on-farm research program. CIMMYT's Regional

Economist and Maize Agronomist for Central America and the Caribbean began work in Haiti shortly thereafter and, in 1981, the Economics Program assigned a full-time resident staff member in Haiti to intensify CIMMYT's collaboration with the national program (initially with funding from the Rockefeller Foundation and the Swiss Government and later with support from CIDA, Canada).

Small-scale agriculture characterizes the Republic of Haiti. Approximately 75% of the nation's 6 million inhabitants reside in the rural areas, and over 900,000 ha are cultivated annually. Population density in the countryside is quite high, approximately 470 persons/km<sup>2</sup> cultivated, and the GNP per capita is among the world's lowest (estimated at U.S. \$300). Land scarcity, population pressure and the country's difficult socioeconomic situation suggest that technological change might play an important role in improving the productivity and income of Haitian farmers.

In this context, an area-specific on-farm research (OFR) program was defined for the Les Cayes region in southwestern Haiti. Maize was selected as the target crop, since it is the most important grain in the region and in the country. National maize production is estimated at over 250,000 metric tons (t) and occupies 30% of all cultivated lands (followed by sorghum and rice).

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The goals of the program were two-fold: (1) to generate improved and appropriate maize technologies to increase productivity and income of representative farmers in a reasonably short period of time and (2) to serve as a source of concrete experience which could help guide the Haitian national research program in establishing OFR operations at the national level. In this context the project in Les Cayes was to be closely monitored and evaluated throughout its development.

### **Defining recommendation domains and research opportunities**

—Following CIMMYT's sequential strategy for developing appropriate technologies through OFR, the team in Les Cayes immediately began an analysis of "farmer circumstances," as the 1981 planting was less than one month away. A rapid exploratory survey allowed the identification of

some priority production constraints offering promising research opportunities and the definition of some tentative "recommendation domains," or roughly homogeneous groups of farmers for whom a single recommendation might eventually be made. The variability in farmer circumstances and in observed production practices made it difficult to make a rapid definition of recommendation domains, though some basic lines of differentiation between farmers were identified (e.g., hilly vs. flat topography, rainfed vs. irrigated fields) and some tentative domains outlined.

The decision was taken to focus research initially in one recommendation domain, briefly described as farmers producing monoculture maize in flat non-irrigated land. Representative farmers and prevailing practices for this domain were outlined through the informal and later the formal



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surveys, and some important production constraints and priority research opportunities were identified.

This information was used to design the initial experiments in the farmers' fields. This led to a research focus on four key themes: variety, fertilizers, plant population and weed control. A more thorough survey of randomly selected farmers was made some months later, and the quantification of key variables permitted the team to verify as well as modify the initial hypotheses.

**First cycle of experiments**—Variety and exploratory trials were planted to test the hypotheses formulated at

the planning stage. Five variety trials evaluated ten improved maize varieties and two local varieties. Using survey data, all the new materials were prescreened to meet both agronomic requirements (e.g., maturity) and farmer preferences (e.g., color, grain type). Eight exploratory trials incorporated the remaining experimental variables on fertilizers (nitrogen and phosphorus), plant population, and weed control. Each variable had two levels, the first representing the prevailing farmer practice for the recommendation domain and the second an experimental alternative believed feasible for local farmers and yet one that would still allow the detection of significant effects



Haiti's program of on-farm research has increased the capacity of national research institutions to generate appropriate technologies for target groups of farmers.

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and interactions, should they exist. The exploratory trials attempted to: (1) verify the hypotheses about the importance of the research opportunities identified in the survey phase and (2) assess the feasibility of new technological components considered as potential alternatives to prevailing farmer practices.

**Results from cycle I**—Nitrogen had a highly consistent positive effect across locations. On average, yields increased 960 kg/ha (from 1.5 t/ha). Phosphorus and plant population were significant factors in only 25% of the experiments and the effect on yield of chemical vs. manual weed control was close to zero. Actually, this result seemed likely at the time of the exploratory survey because of the very low opportunity cost of labor. Even so, the component was included to satisfy doubts within the research team regarding its relevance.

Approximately one-half of the maize farmers interviewed were sharecropping some maize. Typical arrangements have the sharecropper giving 50% of the harvest to the landowner, though fertilizer costs are generally not shared. Sharecroppers, therefore, would get only half the benefits of fertilizer use, though they must pay all the fertilizer costs should they decide to use fertilizer. Under these circumstances the economic returns to nitrogen fertilization are dramatically different for landowners and for sharecroppers.

The type of fertilizer available was also important. The Department of Agriculture in Les Cayes was selling fertilizers at U.S. \$10 per 100 lbs, regardless of formula. However, even though urea was clearly the cheapest source of nitrogen, it represented only a small percentage (4%) of the total fertilizer available in Les Cayes. Rates of return were accordingly computed for two nitrogen-pricing scenarios, one using urea as the source of N, and the other using the most widely available fertilizer, 18-8-20. Results shown in Table 1 indicate that for "landowners," the marginal rates of return to 80 kg N across locations were on average 279% and 115%, depending on whether the source of nitrogen was urea or 18-8-20. In the case of sharecroppers, only urea offered a profitable return.

A similar analysis was conducted for the variety trials. The highest yields across locations were obtained with the improved varieties La Maquina 7827 and La Maquina 7928, both yielding approximately 1 t/ha more grain than the best local maize variety, Chicken Corn, in all locations but one. Both improved varieties were very similar to the local maize in terms of important agronomic characteristics (e.g., days to flower, plant and ear height).

Given these results and the information from the farmer surveys, the quality, color and taste of the ground maize were also evaluated (here the opinions of the

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rural women were especially sought out, as they dominate both food preparation and maize marketing activities). Both La Maquina varieties compared well with the local maize in these important tests. This was especially so for La Maquina 7827 which was rated significantly higher than Chicken Corn by survey participants for taste, color, milling quality and ease of shelling.

**Implications for further research:**

**cycle II**—The convergence of experimental results and the information from subsequent farmer surveys permitted the team to verify/adjust the research hypotheses formulated through the survey process. This in turn led to a “fine tuning” of the experimental strategy for the second cycle.

The hypotheses about variety and nitrogen fertilization were confirmed and would continue to figure prominently in further research, and two sets of modified exploratory and variety trials were planted in Cycle II. With regard to phosphorus and plant density, both had inconclusive effects on yields in Cycle I. While they did not apparently offer as promising a research opportunity as nitrogen and variety, both components were important in some locations and further evaluation was considered necessary before a final determination was made on their continuing role in the research program.

Method of weed control, the remaining experimental variable, had the least effect on productivity of all components tested. Chemical control did not offer important cost advantages over present methods of manual control since, as the formal study demonstrated, access to manual labor was not generally an important production constraint. Chemical weed control also did not offer important advantages in terms of timeliness of weeding. The experimental results combined with the survey analysis suggested dropping this line of research so as to economize on research resources. Variety replaced weed control as an experimental variable in the exploratory trials of Cycle II.

**Results from cycle II**—The results from Cycle II experiments in different locations within the target recommendation domain strongly confirmed the earlier conclusions. Yield response to N was again statistically and economically significant in all locations, though both phosphorus fertilization and plant population had only minimal effects (non-significant) on yield (close to zero across locations). The effect of variety was not as strong as nitrogen but was still positive in all locations but one, and differences in yield by variety were statistically significant across locations.

An economic analysis of the application of nitrogen fertilization was again carried out, taking into account important changes in both



the field price of nitrogen and maize. No subsidized urea was available in 1982, and the cheapest source of N was free market urea, which was priced at 85% above the previous year. The field price of maize, on the other hand, had dropped 28%. Despite these critical constraints, 80 kg N/ha was profitable for landowners across locations, especially for the improved variety La Maquina 7827, but also with the local maize.

In the variety trials, where fertilizer was applied, the two La Maquina varieties outperformed Chicken Corn by an average of 500 kg/ha (during 1982-83). Even without nitrogen, the La Maquina varieties yielded on average 120 kg/ha or 10% more than Chicken Corn, an indication of the "genetic" effect of the improved variety alone.

**Implications for further research: cycle III**—The consistency of results from Cycles I and II permitted a considerable advance towards the formulation of farmer recommendations. Field work in Cycle III could concentrate on a more rigorous agronomic and economic analysis of the two most promising technological components, nitrogen fertilization and variety, with an eye towards refining recommendations. This steady and dynamic process of refining the research parameters while intensifying the focus of the research (in response to the on-going analysis of new information) is illustrated in Figure 1.

Two kinds of experiments were planted in Cycle III: verification trials related to variety and nitrogen responses and levels of fertilization. In the verification trials, farmers

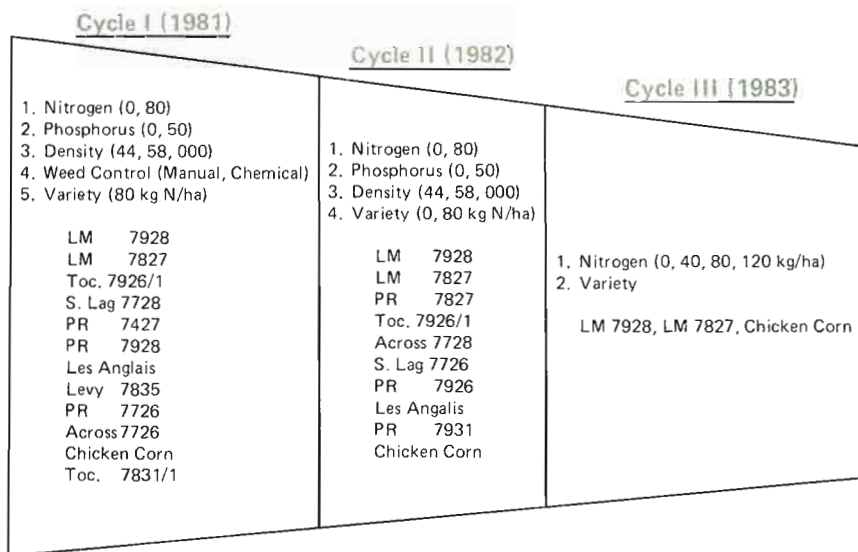


Figure 1. Narrowing of the research focus after three cycles of experiments

planted half a field with the best local variety, Chicken Corn, and half with La Maquina 7827, giving the same management to both varieties. Nitrogen fertilization was later superimposed by the research team across both varieties in half of each field. This gave four simple subplots contrasting the two key components. All other management was in the hands of the farmers themselves. The results from these farmer-managed trials were quite

consistent with those of Cycles I and II. The yield response to N was again important for both varieties.

Analysis of the “nitrogen levels by variety” verification trials suggested that 40 kg N/ha would be the most appropriate level of nitrogen fertilization for the target recommendation domain, regardless of the variety planted (Figure 2). Yield differences between varieties were statistically and economically

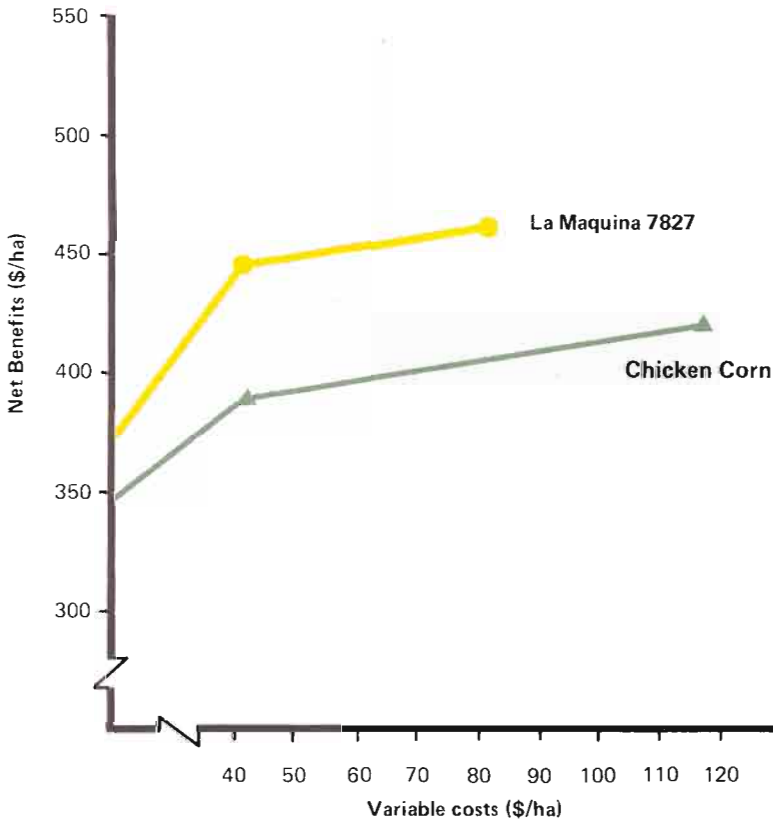


Figure 2. Net Benefits Curve. Average returns to nitrogen for La Maquina 7827 and Chicken Corn at 4 levels of fertilization (Source of N = urea at US\$18/100 lbs)

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significant in all locations with both of the improved La Maquina varieties out-yielding the local varieties at every level of N. This suggested it could be possible for the Department of Agriculture to make independent recommendations for both variety and for nitrogen fertilization, and this could have important implications for the rate of diffusion.

The research process revealed two important qualifications to a general nitrogen recommendation:

- 1) The source of N must be urea, rather than the Department of Agriculture's subsidized blends. The results from Les Cayes suggested that present fertilizer policies may be less than optimal for the large majority of maize growers in the Cayes Plain. The program thus clearly identified a policy constraint (fertilizer supplies and distribution) linked to the maximization of potential benefits with improved technology (urea). This underlines the broad scope and applications of the research methodology.
- 2) The nitrogen recommendation applies only to fields planted by landowners, or by sharecroppers who pay only those fertilizer costs proportional to their share of the yield. However, the present cost-sharing arrangement could change, over time, as more landowners become aware of the benefits associated with urea fertilization.

### **Impact of the Les Cayes**

**program**—Farmer recommendations for variety (La Maquina 7827) and for nitrogen fertilization (40 kg N/ha for landowners, using urea) were made by the Department of Agriculture in early 1984, and initial signs of adoption have been encouraging. The Department has placed increasing emphasis on the production and distribution of La Maquina 7827 seed.

An expanded extension effort to promote the two recommendations is now in the planning phase, and the private sector has already reported rapidly increasing sales of urea (though a more thorough analysis will be needed to determine how much of this urea is being used for maize, how much for other crops).

Meanwhile, the team in Les Cayes has begun to address other important production constraints, such as seed multiplication, and pursue new research opportunities, especially methods of land preparation. Collaboration continues with the Levy Farm experiment station staff, although the work there has undergone an important evolution since the program began. Today the results from the experiments in farmers' fields help guide the Levy staff in their station research, breeding and seed multiplication activities, which will make future products from the station-based research more relevant to the needs and capabilities of the area farmers.

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**The national response**—In late 1983 the Secretary of State for Agriculture and Natural Resources called for an evaluation of the Les Cayes program. During 1984, interviews were conducted with over 60 collaborating farmers. The principal recommendations from the evaluation team were:

- 1) This type of program should be carried out in other parts of the country and with other target crops, and
- 2) Increasing emphasis should be given to in-service training of Haitian researchers in these particular research procedures, in order to permit an increasing national commitment to this kind of research.

CIMMYT hopes to intensify collaboration with the Haitian national program in order to help meet these important goals. In particular, plans are under way to launch a more comprehensive in-country training effort in 1985, as part of the project's overall efforts to institutionalize OFR in Haiti, and thereby contribute in an important way to increasing the capacity of the country to generate appropriate technologies for target groups of farmers.

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## Research Resource Allocation

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In establishing priorities for agricultural research, policy makers must consider a myriad of policy concerns including economic development, income distribution, food security, foreign exchange and the environment. One analytical tool that can be used in this process is based on comparative advantage, which indicates the ability of different enterprises to contribute to national income in a country.

Explicitly, or implicitly, farmers assess the profitability of different enterprises using prices they face at the farm gate. Production decisions taken by farmers are based on expectations of prices, yields and input requirements for particular enterprises, as well as other economic, biological and social considerations. Rarely, however, does the profitability faced by farmers closely reflect the profitability to the nation. Subsidies, taxes and exchange rate anomalies often significantly influence farmer prices. Empirical analysis of comparative advantage involves removing these effects and calculating profitability to the nation of different enterprises. A basic question addressed in comparative advantage analysis is whether it is cheaper in terms of domestic resources used for a country to import goods than it is to produce them domestically.

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Once the effects of subsidies and exchange rate anomalies are removed, true costs of production can be estimated for a given range of crops and technologies. Here, biological and economic research data, gathered and/or confirmed through on-farm research, can add valuable information on the nature of trade-offs between competing farm enterprises in defined environments. Further, such analysis can help make more explicit the challenges that researchers face in shifting the production function for a given crop or farm enterprise, i.e., the yield and profitability threshold levels needed to make a particular enterprise profitable in a given environment.

The analysis of comparative advantage can also provide information on the types of technologies to be pursued in particular regions (e.g., labor-intensive, water-saving) or across regions (e.g., emphasize dryland research more). We believe that data and analysis of this kind will be useful to research resource managers, giving them a more refined sense of where and to what crop allocations should be made.

CIMMYT Economics staff are conducting a series of case studies in various developing country regions. These studies are being prepared in collaboration with

scientists and economists from national institutions who are involved in agricultural research planning. Using the experience of these case studies, a manual will be prepared which outlines the research approaches employed in assessing the implications of comparative advantage (and departures from it) for agricultural research resource allocation. The manual will be the basis for training national program researchers to undertake this activity. Following are highlights of two wheat-related studies undertaken in Ecuador and in Thailand during 1983-84.

#### **Comparative Advantage and Policy Incentives for Wheat Production in Ecuador**

During the last decade in Ecuador, the production of wheat, the most important staple grain, has decreased sharply at the same time that consumption has been increasing rapidly. As a result, wheat imports have grown at 12% annually from 1970 to 1982 and Ecuador now imports over 90% of the wheat it consumes.

Three major questions were addressed in the study: (1) Why has wheat production fallen and imports increased so rapidly in Ecuador? (2) What levels of technological change are needed to make wheat competitive? (3) In the face of these findings, what can be said about the level of resources committed to wheat research? The study was conducted in the Cayambe region, northeast of Quito and traditionally the most important wheat-growing region in Ecuador. In this region, wheat yields average 1.5 t/ha but using a recommended technology could achieve 2.5 t/ha.



Producer prices of wheat in Ecuador in the past decade declined sharply in real terms and in relation to prices of competing crop and livestock commodities. The decline in the price of wheat arose largely from a policy of linking producer prices to the import price of wheat at the official exchange rate which itself was significantly overvalued in the period 1977 to 1983. In the case of milk production—the most important alternative use of land—prices were fairly steady in real terms for much of the decade. Moreover, imports of dairy products were constrained by restrictions and faced an exchange rate more favorable to producers than the one applied to wheat. The producer price for barley also rose relative to wheat, also due to import protection. Overall, in the period 1970-83, the price of wheat declined 30% relative to barley and about 50% relative to milk. This is a case, then, in which prices have been influenced by policy and in which farmer and national profits probably differ.

The profitabilities of wheat and competing crop and livestock activities were compared at two levels of technology: (1) current farmer technology and (2) an improved level of technology. This comparison was restricted to two different systems in the Cayambe area: a) valley bottoms where irrigation allows intensive dairy farming with improved pastures or where two crops per year can be produced and b) hillsides without irrigation where only extensive

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relatively low productivity dairying with natural pastures is practiced or where usually only one crop per year can be grown.

**Research results**—Under current prices and technologies, farmers' returns to land in wheat production were slightly less than for other cereals and less than half of the returns in dairying and potatoes.

While high capital and labor requirements and price risks of potato production have limited expansion of that crop, there has been a substantial shift in land use toward both intensive and extensive dairy farming.

Price policy has also been a factor in the stagnant yields in wheat production in recent years. While farmers have accepted improved wheat varieties (and probably prevented a decline in yields due to diseases), most farmers apply fertilizer doses well below recommendations as economic returns to fertilizer use in wheat are modest given current prices.

When the effects of these policy prescriptions are removed, by calculating national profitability of each crop and livestock enterprise, wheat provided the highest returns to land, after potatoes, and extensive dairying the lowest.



Comparative advantage analysis has shown that price policy has been detrimental to wheat production in Ecuador, which now imports 90% of the wheat it consumes.

Wheat yields were varied in the profitability analysis. On the hillsides, wheat yields of 1.6 t/ha with moderate doses of fertilizer are needed to compete with extensive dairying. In the valley bottoms, wheat competes with intensive dairying when compared at either current farmer or improved levels of technology. In each case, wheat also provides higher returns than barley, for barley requires similar levels of inputs but its import price is usually below that of wheat.

The differences between farmers' returns, which are low for wheat, and returns to the country, which are relatively high, are due to the effects of subsidies, taxes, and exchange rate anomalies. Overall, net policy effects taking into account effects on product and

input prices and capital costs are significantly negative for wheat, zero for barley and positive for dairying and potatoes.

Taken alone, the results provide a basis for continuing a strong wheat research program in Ecuador. Although technological change alone is not sufficient to overcome the low farmer returns from wheat under current policies, agricultural research is a long-term process and decisions on research resource allocation must take a long-term perspective on the policy environment. In this case, it seems especially unlikely that the foreign exchange anomalies will be maintained, which will reduce pasture's relative profitability and increase that of wheat, implying a demand for improved wheat technology.

**Table 1. Estimated profitability to farmers and to the nation of wheat and competing enterprises at recommended technology levels, Cayambe, Ecuador, 1983**

Enterprise	Farmer Returns to Land	National Returns to Land	Total Policy Effect <sup>b/</sup>
	-----Sucres/ha-----		
Wheat	13,360	23,330	9,960
Barley	13,880	14,620	740
Potatoes	64,200	45,300	-18,900
Intensive Dairying <sup>a/</sup>	26,550	18,850	-7,700
Extensive Dairying	15,540	12,830	-2,710

a/ Expressed per 6-month cycle

b/ Difference between farmer and national land returns



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## **Wheat in Chiang Rai, Thailand: A Preliminary Look at Comparative Advantage**

**Background**—Thailand, like many other tropical countries, is importing and consuming ever-increasing amounts of wheat. Currently produced domestic wheat could substitute for some 20,000 t/yr of imported wheat. Moreover, there is a potentially strong market for wheat in “local preparations” in isolated northern regions. These give evidence of a potential market for domestic production. As a consequence, Thai researchers, in cooperation with CIMMYT, have begun to look into the possibilities of producing wheat locally. To date economics research has focused on a preliminary assessment of the comparative advantage in parts of northern Thailand, particularly in Chiang Rai Province for wheat.

Several factors point to northern regions as being the most suitable for wheat growing in Thailand, especially those areas with a longer cool season, adequate rainfall, and land left uncropped at that time of the year. While there are large differences with respect to cropping patterns, moisture availability, soil type and agronomic possibilities in Chiang Rai Province, four potential wheat production domains were identified initially for study.

Each of the potential production domains was then examined in the light of several questions: (1) which potential wheat production domains in Chiang Rai Province are nearest to a comparative advantage in growing wheat and (2) what wheat yields must be achieved in a given domain to give a comparative advantage to the production of wheat.

Early analysis showed that in only two of the potential domains in Chiang Rai Province did wheat have a good chance of becoming competitive. In the two eliminated,



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wheat would have to compete with irrigated rice or with high-value crops such as garlic and tobacco. Detailed study, therefore, was restricted to two regions; briefly, they are described as:

- 1) Rainfed upland: cropland is not banded, not irrigated, growing maize in the rainy season, and growing a second crop where rainfall is adequate in the cool season (maize in the favored areas, and mung beans or peanuts in the less-favored areas). Accounts for some 55,000 ha in the province.
- 2) Lowland, inadequate dry season water: banded cropland growing rice in the rainy season but with poor water control and without

reliable water in dry (cool) season, so generally not cropped in this season. Area is about 200,000 ha in the province.

In this study, the policy effects were minimal so relatively few adjustments to prices were necessary. The main adjustment was in the price of wheat, to account for an import duty of about 23 percent. Other important prices, including exchange rates, are approximately those of an open economy. The focus of the study was on the potential profitability of wheat, which is essentially a new crop in Chiang Rai Province, compared with alternative traditional crops. It was possible to make only preliminary assessments of comparative advantage, due to a



With varieties that fit the environment better, wheat could become a commercial crop in the upland regions of Thailand.

lack of data on wheat-growing practices. This lack of data is to be expected when dealing with a new crop being introduced into a nontraditional area. Nevertheless, the approach followed makes it possible to incorporate the judgments of technical researchers about "reasonable" wheat production practices, yields, and input requirements based on the experimentation already undertaken. More important, the approach makes it possible to estimate the increases in productivity needed to give a domain a comparative advantage in wheat. Then, researchers can judge the probable research cost of attaining those increases through improved technologies.

**Research results**—The results of analysis for the two domains studied were framed so as to be especially useful to plant breeders and agronomists. Table 2 presents the estimated yield levels necessary to make wheat competitive with other crops in the upland domain

and to cover costs (no other crops are grown in the dry season) in the lowland domains. For both situations, estimated required yields are given under current farm prices and for the price regime that would prevail were there neither subsidies nor direct taxes.

Wheat yields of 1,000 kg/ha are now possible in the upland domain with appropriate input combinations. At current farm gate prices, this would make wheat an attractive alternative for farmers as yields exceed the 960 kg/ha needed to make wheat competitive. The advantage of wheat is small—some 40 kg/ha—so it is unlikely that many would want to switch to wheat with the current technology. Although wheat does not now compete with other crops, with varieties that fit the environment better (and breeders have a fairly good idea of what is required if varieties are to compete), wheat could easily become a commercial crop in the upland region.

**Table 2. Wheat yields needed to make wheat enterprise competitive, Chiang Rai Province, Thailand, 1984**

	At Farmer Prices	At World Price Equivalent
	-----kg/ha-----	
Rainfed upland domain	960	1,150
Wetland domain, with water shortages in dry season*	640	770

\* Assumes timely planting

Source: Harrington, L.W. and Sudarat Sat-thaporn, 1984

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In the lowland region, it is estimated that yields of 1000 kg/ha at low-levels of inputs are also attainable but only if wheat is planted at a particular time. That timing is difficult to affect with the rice varieties currently used as the soils are still saturated or covered with water from the preceding wet-season rice crop. Some combination of higher wheat yields and shorter-season rice varieties plus improved generalized water control will be needed to bring wheat into production in this region. With better-adapted wheat varieties and higher wheat yields, farmers could justify moving to shorter-season and somewhat lower-yielding rices and also bring into play the needed improvements in water control.

In each case, then, apparently attainable yield changes for wheat could bring the crop into production. However, the added complexity in the lowland domain suggests that early priority should go to the upland domain, where only modest yield improvements could make wheat an appealing alternative crop, both for farmers and the nation.

### References

Byerlee, D.R. "Comparative advantage and policy incentives for wheat production in Ecuador." CIMMYT Economics Program Working Paper, No. 01/85, February, 1985.

Harrington, L.W. and Sudarat Satthaporn. "Wheat in Chiang Rai, Thailand: a preliminary look at comparative advantage."

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## Data Collection and Analysis

The Economics Program has two serial publications which contained the results of data collection and analysis on the maize and wheat world economies. These reports assemble, on a regular basis, pertinent data related to maize and wheat production, prices, utilization and trade, and present this information in a readily digestible form for agricultural researchers, administrators and policy makers. In addition, in each report one or more specific issues are analyzed in greater detail.

### An Analysis of Changes in Third World Food and Feed Uses of Maize

In 1984, CIMMYT published "World Maize Facts and Trends Report Two: An analysis of changes in Third World food and feed uses of maize." This report consists of three major sections. The first provides a description and analysis of changes in maize utilization and trade in the developing world. Section two provides an overview of the current global maize production, trade and price situation. Section three presents in tabular form selected statistics related to maize production, utilization and trade for countries that either grow over 100,000 hectares of maize or utilize annually over 100,000 tons of maize (or both). Highlighted here are the pertinent trends from this report.

### Trends in Third World

**utilization of maize**—In terms of total production, maize ranks second to wheat among the world's cereals crops. Global production of maize now normally exceeds 400 million tons (Mt) per year, compared with almost 500 Mt for wheat.

During the period 1970-72 to 1981-83, global maize production increased by approximately 120 Mt. This is a 3.1% annual growth rate and represents a 42% increase in world supplies (Figure 3). Developing countries achieved an average production growth rate of 3.6%, higher than the global growth rate, although there was considerable variation by region.

**Utilization**—Globally, about two-thirds of total utilization of maize is for feeding livestock, while a quarter is for human consumption and industrial purposes (Figure 4). (The balance is used for seed or is lost in wastage.) Just over 40 percent of total world utilization of maize occurs in the developing world. Developing countries report an average utilization of 50 kg/capita per year (55% used for human consumption) as compared with just under 275 kg/capita per year (90% used for animal feed) in developed market economies.

The direct human consumption of maize as food generally grew at a slow pace during the past decade,

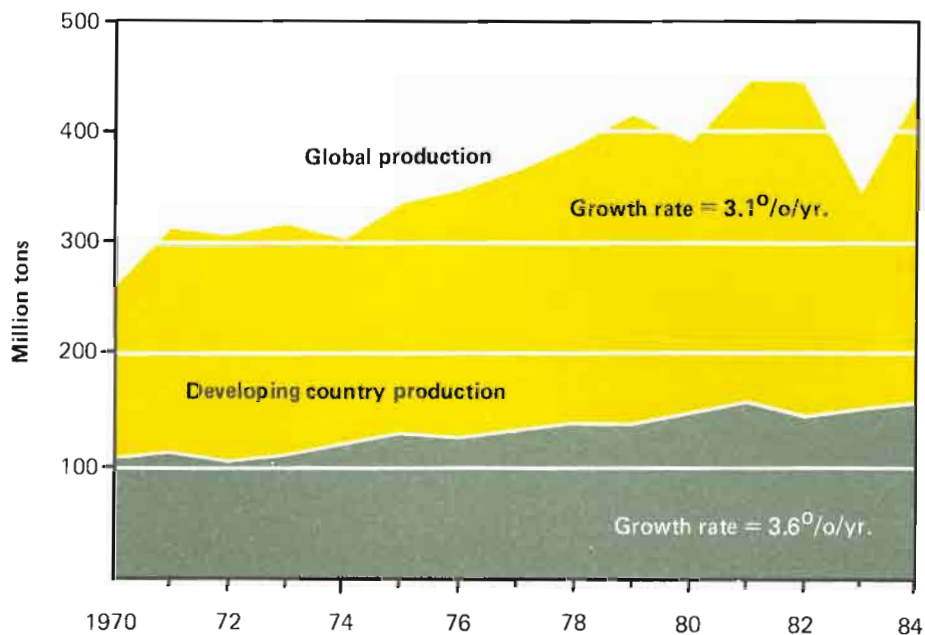
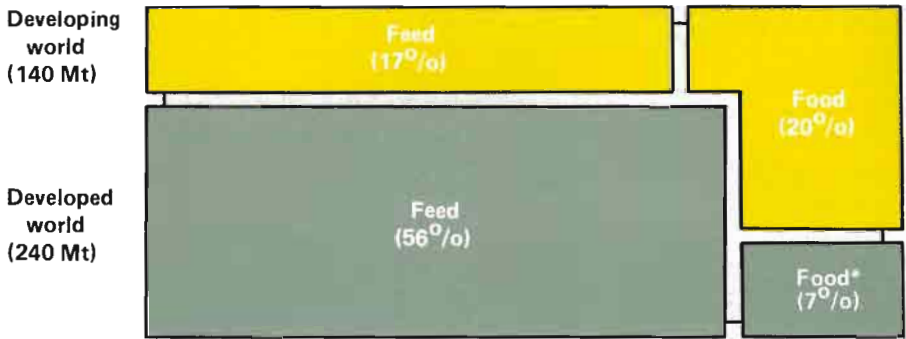


Figure 3. Developing country and global maize production, 1970 to 1984



\*Includes use of maize in the production of sweeteners

Total feed and food use = 380 million tons

Figure 4. The use of maize for food and feed in the developed and developing world, 1980-81 and 1981-82 average

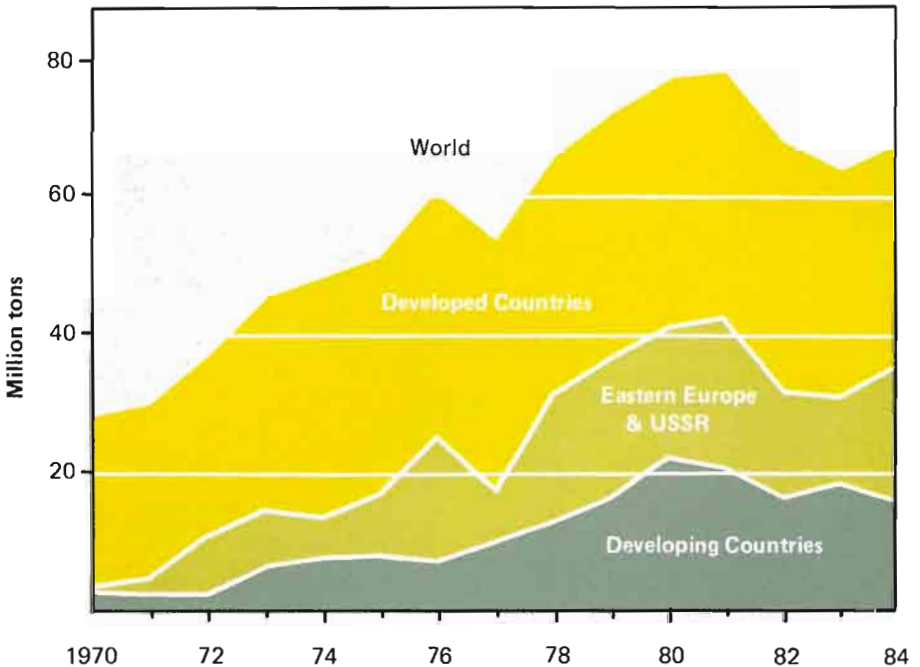


Figure 5. World Imports of maize by region, 1970 to 1984

while there were rapid gains in its use as a feedgrain. Globally, direct consumption of maize increased at 1.6% per annum, well below the 3.7% average yearly gain in maize use for feed, and below the annual increase in world population.

Significant longer-term changes are occurring in the uses of maize throughout the developing world. As incomes rise, Third World consumers are spending a higher proportion of their food budget on livestock products and less on maize as a staple food in their diet. The most important factor boosting demand for livestock and poultry production in the developing world is the upward trend in incomes, and

the related changes in urbanization and in lifestyles. Many studies indicate the strong influence of changes in income levels on the meat and poultry consumption in the developing world (Table 3).

As evidence of this changing demand, during the decade of the 1970s, developing countries registered annual growth rates of 1.7% for food use and 5.3% for feed use. Throughout Asia and the Middle East, feed use has grown at more than three times the rate of direct human consumption. In Africa, maize feed use has increased almost twice as rapidly as food, although feed use remains relatively low.

**Table 3. Impact of a one percent change in income on the consumption of eggs, poultry meat, and pork, 1980**

Country	1977 Income/capita (\$US)	Percentage change in consumption of:		
		Eggs 1980	Poultry meat 1980	Pork 1980
<b>Asia</b>				
Bangladesh	up to 250	.06	1.7	0
India	up to 250	1	1.5	0.8
Indönesia	250-499	1.2	1.5	0.8
Philippines	250-499	1	1	0.93
Malaysia	500-1,249	0.73	0.87	0.11
Hong Kong	more than 1,250	0.15	0.68	0.08
<b>Latin America</b>				
Haiti	up to 250	1	1.5	1
Honduras	250-499	1	1	0.5
Guatemala	500-1,249	0.8	1	0.6
Mexico	more than 1,250	0.59	0.93	0.49

Source: Sarma, J.S., IFPRI, Washington, D.C., personal communication

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**Trade**—Total global trade in maize during 1980-82 averaged just over 76 million tons per annum (Figure 5). (Wheat was just under 100 Mt; other coarse grains 20 Mt; rice, about 11 Mt.) World trade in maize has more than doubled over the period 1970-72 to 1980-82, from 33 Mt to 76 Mt, a growth of 8.9%

per annum. A notable feature of this growth was the rapidly increasing reliance of the developing countries on exports from the developed countries. During the 1970s, developing country imports of maize increased six-fold, from just over 3.5 Mt during 1970-72 to approximately 20 Mt per year



A common consequence of economic development is a decline in per capita food use of maize.



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during 1980-82. The most rapid import growth rates in the developing world have been registered by the newly industrializing nations that are not major producers of maize, who use maize in intensive livestock and poultry production.

**Conclusions**—The decline in food use of maize and the increase in its use for feed in developing countries is a favorable consequence of economic development. This switch from maize as a food grain to maize as a feed grain suggests that there is considerable potential for expansion in the use of maize in the developing countries. This stems from the considerable leverage involved in the switch from direct consumption of maize to indirect consumption through livestock products. For example, 50 kg of intensive livestock products is basically 150-200 kg of transformed feed grains and supplements.

Population, income and urban growth rates in the Third World will dictate the pace at which the demand for maize as a livestock feed increases. The potential is enormous, however, for growth in the use of maize as a feed grain in the developing world for the remainder of this century.

As far as satisfying that demand, current average yields of maize in most developing countries are low. Given the very high yield potential of maize—even in the tropics—and its broad environmental adaptation, it is clear that the continuing development of well-focused maize research and production programs, coupled with appropriate food and agricultural policies, can result in significant productivity increases in much of the developing world in the coming decades.



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