CIMMYT

Wheat Breeding at CIMMYT:

Commemorating 50 Years of Research in Mexico for Global Wheat Improvement

Ciudad Obregón, Sonora, Mexico
21-25 March, 1994

S. Rajaram and G.P. Hettel
Editors

Wheat Special Report No. 29

CIMMYT

Wheat Breeding at CIMMYT:

Commemorating 50 Years of Research in Mexico for Global Wheat Improvement

Ciudad Obregón, Sonora, Mexico
21-25 March, 1994

S. Rajaram and G.P. Hettel
Editors

International Maize and Wheat Improvement Center
CIMMYT

CIMMYT is an internationally funded, nonprofit scientific research and training organization. Headquartered in Mexico, the Center is engaged in a worldwide research program for maize, wheat, and triticale, with emphasis on improving the productivity of agricultural resources in developing countries. It is one of 16 nonprofit international agricultural research and training centers supported by the Consultative Group on International Agricultural Research (CGIAR), which 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 a combination of 40 donor countries, international and regional organizations, and private foundations.

CIMMYT receives core support through the CGIAR from a number of sources, including the international aid agencies of Australia, Austria, Belgium, Brazil, Canada, China, Denmark, Finland, France, Germany, India, Italy, Japan, Mexico, the Netherlands, Norway, the Philippines, Spain, Switzerland, the United Kingdom, and the USA, and from the European Economic Commission, Ford Foundation, Inter-American Development Bank, OPEC Fund for International Development, UNDP, and World Bank. CIMMYT also receives non-CGIAR extra-core support from the International Development Research Center (IDRC) of Canada, the Rockefeller Foundation, and many of the core donors listed above.

Responsibility for this publication rests solely with CIMMYT

Correct Citation: Rajaram, S., and G.P. Hettel, eds. 1995. Wheat Breeding at CIMMYT: Commemorating 50 Years of Research in Mexico for Global Wheat Improvement. Wheat Special Report No. 29. Mexico, D.F.: CIMMYT.

ISSN: 0187-7787
ISBN: 968-6923-38-1
AGROVOC descriptors: Wheats, soft wheat, hard wheat, plant breeding, selection criteria, resistance to injurious factors, drought resistance, disease resistance, research institutions, research projects, Mexico
AGRIS subject code: F30
Dewey decimal classification: 633.1153

On the cover: Norman E. Borlaug (right), the 1970 Nobel Peace Prize Laureate, observed his 50th year of "listening to the wheat plants" in Mexico during 1994. Here, he confers with Sanjaya Rajaram, CIMMYT bread wheat breeder, in the plots at Ciudad Obregón, Mexico.
Photo by Gene Hettel

Contents

Preface

Norman E. Borlaug, CIMMYT Consultant

I am pleased to provide the preface to this Special Report on wheat breeding at CIMMYT commemorating 50 years of research in Mexico for global wheat improvement.

During 1994, I observed my 50th year of working in the fields of Mexico. How is it in the first place that a major research program on wheat was started in 1944 in Mexico, the home of maize? Few know that wheat was brought to Mexico in early colonial times by the Spanish. When I arrived in the country, 60% of the wheat was imported. Prior to my arrival in the State of Sonora in northwestern Mexico, Governor Rodolfo Elías Calles was tremendously enthusiastic about agriculture and he established a modern 100-hectare farm with excellent buildings, a good set of machinery, and the best livestock that money could buy. The talented Edmundo Taboado managed the farm for the first couple of years and he was particularly interested in wheat. He had introduced some 30 or 40 varieties from other countries for testing and chose and multiplied the Italian variety Mentana as being superior to all of the varieties then being grown commercially. Ing. Taboado also initiated a wheat breeding program that crossed the best introductions to the best "landraces" or "local" varieties. Then he was called to Mexico City to organize the whole agricultural research program for the Ministry of Agriculture. Because of Taboado's efforts, farmers in northwestern became much more interested in wheat. Unfortunately, inexperience in breeding for disease resistance by those left in charge led to disastrous stem rust epidemics in 1939-41 that essentially wiped out the whole crop. This was the environment in which I found myself when I arrived to establish a wheat breeding program in Sonora.

Needless to say, the animosity of the farmers towards anyone who was involved with the agricultural sciences was pretty high. We were ignored—maybe that was the best treatment at the time as far as we were concerned. In those days, it took 10 to 11 years to develop a rust-resistant wheat variety. The dogma of the time dictated that, in order to have a variety that was adapted, a breeder had to make a cross and then make all subsequent selections in the soil and climatic conditions under which the variety was to be grown commercially—that meant one generation a year. When I had seen that there had been three successive stem rust epidemics in the main wheat growing area of Mexico, only three years before I arrived, I knew I didn't have 10 or 11 years before the next epidemic, and when it did occur I would be thrown out of the country.

To speed up the breeding process, I started what was later to be called "shuttle breeding". With this methodology, segregating populations were planted on the irrigated coastal plain in the Yaqui Valley of northwestern Mexico (at 27.5°N latitude and 30 masl) in November when the days were getting shorter. We created artificial rust epidemics and selected the best plants for height, rust resistance, and grain type. We then "shuttled" the resulting seed back to the high elevation (2650 masl) of the Toluca Valley (17.5°N latitude) for planting in early May when the days were growing longer. In four and a half years, we had the first varieties, which were very good ones. We used the same shuttling procedure to accelerate the first two seed multiplications.

All this took place before there was knowledge of photoperiodism and its importance in cereal grains. It had been known for several years when I was in graduate school that photoperiod was important in

certain kinds of floricultural and horticultural crops, but it was thought that cereals were not very sensitive. However, it turned out quite differently.

How did this little wheat breeding program in Mexico have such a big impact in so many places around the world? Mexico itself became self-sufficient in food production in 1956. By 1959, I turned the wheat breeding program over to my young Mexican colleagues and I considered becoming a banana breeder in Central America. But the Rockefeller Foundation had other ideas. They sent me on a short assignment to work with the FAO to look at wheat production problems in North Africa, all of the Middle East, and India and Pakistan. As I traveled through these regions, I saw a shortage of trained people. However, in India and Egypt, I saw many young people who had fresh doctorates or masters degrees from Europe, Canada, the U.S., Australia, and many other different places. So, I made a proposal that we bring young scientists from these countries, who had just finished their university training, to Mexico for an intensive 6-month training course in plant breeding, plant pathology, agronomy, soil irrigation, and cereal technology. The idea was approved and the first trainees (an outstanding group of individuals) came to Mexico in the fall of 1961. Each year after that, a new group came.

During this early period, we organized the First International Wheat Yield Nurseries with the help of the trainees, who had sent to Mexico about 200 g of the main wheat varieties of their home countries. The seed was disinfected and grown in seed plots. The seeds harvested from these plots were incorporated into an International Yield Nursery. This nursery was sent abroad to many parts of the Near and Middle East. I think that first year there were only 35 locations, but soon there were 75 and then 125. The data that were compiled from these nurseries began to show immediately what we hadn't known for sure before about the importance of photoperiod.

Also included in those first nurseries were the best spring wheats from Canada, North Dakota, South Dakota, Minnesota, and Wisconsin not to mention our own Mexican material and wheats from Guatemala, Ecuador, Peru, Chile, and Argentina. Soon we discovered that the commercial varieties from Canada and the northern U.S., which had good disease resistance and good milling and baking qualities, almost always ranked last in yield in every location under 48° latitude. Yet the Mexican stem rust-resistant wheats yielded well almost everywhere since they were insensitive to day length because they were developed through the shuttle breeding methodology in Mexico.

The Mexican Government-Rockefeller Foundation Cooperative Program was the first foreign technical assistance program in the agricultural sciences. It preceded by five years the Marshall Plan, which assisted the Western European countries in their recovery from the disasters of World War II. It also preceded by six years President Truman's declaration that "the United States has a moral obligation to help developing nations improve their agriculture." So you see the Mexican Program was really a pioneer in this arena.

By the early 1960s, trainees returning home from Mexico always took back with them 10-g samples of any wheats in the Mexican breeding plots they liked. Through letters or through messages carried by other young trainees from the same country who came to Mexico the next year, it soon became apparent that some of these wheats were very promising. There was particular interest in Pakistan and India where food shortages were becoming all to common.

I would like to recognize the scientific contributions of the squadrons of "young" Mexican researchers with whom I have worked over the years. They are not young any longer—many have retired from government service.

In 1963, I was invited by the Government of India to visit its wheat research program. By then, the success story of the dwarf Mexican wheat varieties had spread to many countries in the Near East by the young scientists returning from Mexico. M.S. Swaminathan at IARI had obtained seed of five of the first semidwarf Mexican lines through the USDA International Wheat Stem Rust Nursery and was intrigued by their potential for increasing Indian wheat production. He wanted my opinion on whether these lines might be useful in the Indian breeding program. Since these particular lines were obsolete, I was reluctant to voice an opinion without seeing their performance in the field.

As luck would have it, I would have this opportunity in Pakistan, which was the next stop on my itinerary. And with what transpired there we see the resistance to change that we were up against at that time. I had been invited by the Minister of Agriculture of Pakistan to review their wheat breeding nursery at Lyallpur (now Faisalabad). Now I could see how the lines I saw in India were performing elsewhere in the region. Accompanying us as we visited the experimental plots were two young Pakistani scientists who had been in training program in Mexico. I was disappointed to see the performance of the Mexican semidwarf wheats in the demonstration and breeding plots. They were inferior to the Pakistani wheats under the conditions of the tests. However, I could see that these wheats had been planted at the wrong time and had not been properly fertilized and irrigated, consequently I was sure that the methods used in growing the demonstrations were not optimum for the Mexican wheats under Pakistani conditions. When I mentioned this to the Director of Research, he responded in no uncertain terms that "this is the way wheat is planted in Pakistan."

After dinner, the two young trainees who had accompanied us to the plots that day took me aside and said that they had something to show me in the morning before I left for the airport. In the pre-dawn they awoke me with tapping on my guesthouse window. We walked to the most remote corner of the experiment station and there they were—four plots, 5 m wide by 20 m long, of Mexican dwarf wheats just as beautiful as they were back home in Mexico. I asked why they didn't grow the breeding nurseries with the same technology? They responded that they were not allowed to do so by the experiment station administration.

This story illustrates one of the real obstacles to change. From Pakistan, I went on to Egypt and I found the same thing—some beautiful plots of the Mexican wheats hidden in a remote corner. When the Mexican wheats finally "escaped" from Mexico to be grown commercially in the U.S., it was the farmers themselves and only a few scientists who brought it. The Mexican wheats had taken over 30% of the hard red spring wheat region of northern U.S. before the experiment stations in that part of the country produced their own varieties of high yielding semidwarf wheats.

I will close now by stating that I believe the papers in this special report are of particular importance because they outline the "state of the art" for wheat breeding that will carry us into the next century as we struggle to meet the world's need for food.

Chapter 1.

Wheat Germplasm Improvement: Historical Perspectives, Philosophy, Objectives, and Missions

Sanjaya Rajaram

Evolution of Wheat Breeding at CIMMYT

This year, we celebrate the 50th anniversary (1944-94) of wheat breeding at CIMMYT and its predecessor organization (Rockefeller Foundation/Office of Special Studies). Within a span of 50 years, wheat breeding has evolved through three major strategic phases.

- Bilateral phase (1944-1960) within Mexico;
- Green Revolution phase (1961-76): internationalization of CIMMYT wheat breeding;
- Post-Green Revolution phase (1977-present): globalization of CIMMYT wheat breeding.

Bilateral phase (1944-1960): within Mexico

During this 16-year period, stem rust resistance of a durable nature, derived from the variety Hope and based on the *Sr2* complex (Rajaram et al. 1988), was bred into adapted Mexican germplasm. Thus, the threat caused by this disease was virtually eliminated (Borlaug 1968). Shuttle breeding, a revolutionary breeding methodology (Borlaug 1968), was implemented. This permitted selection of photoperiod insensitivity (based on the genes Ppd1 and Ppd2), which would allow adaptation of the gene pool far beyond Mexico.

Dwarfing genes of Japanese origin (Rht1 and Rht2) were incorporated into the stem rust-resistant and photoperiod-insensitive varieties to reduce plant height. If either Rht1 or Rht2 are present, the reduction is 40 cm (from 130 to 90 cm); if both genes are present, the reduction is 55 cm (from 130 to 75 cm). Consequently, lodging tolerance under optimum irrigation and high fertility conditions was achieved. The outcome of this experiment was revolutionary, and resulted in the production of semidwarf advanced lines showing a yield advance of more than 50% (Hoogendoorn et al. 1988), while maintaining the durable stem rust resistance and photoperiod insensitivity. The essence of wider adaptation of the germplasm had been created.

Green Revolution phase (1961-76): internationalization of wheat breeding

The breeding program was internationalized through the establishment of International Yield Trials and Screening Nurseries in the 1960s. Diverse agroecological regions such as the Indo-Gangetic Plains of the Indian Subcontinent, the Nile Valley, the Mediterranean Basin, the Humid Pampa region of Argentina, and the high rainfall/irrigated Coastal and pre-Cordillera areas of Chile were recognized as requiring focused efforts within CIMMYT's overall mandate.

The major breeding initiatives during this period were the following:

- Exploitation of the spring x winter gene pool with additional assistance through a cooperative venture between CIMMYT and Oregon State University in the USA.

- Septoria leaf blotch resistance in semidwarf wheats with additional assistance through a cooperative venture between CIMMYT, Tel Aviv University in Israel, and IPO, Wageningen, Holland.
- Slow rusting genes to leaf rust were identified, quantified, and bred with initial guidance from Dr. Caldwell at Purdue University, USA.
- Industrial quality characters were emphasized.
- Breeding for resistance to aluminum toxicity was initiated through a cooperative venture between CIMMYT and several Brazilian Agricultural Research Institutes.
- The concept of cooperating more directly with national programs through regional programs was established.
- Breeding programs for durum wheat and triticale were officially initiated.
- Germplasm dissemination through formalized International Nurseries for bread wheat, durum wheat, and triticale were established.

Post-Green Revolution phase (1977-present): globalization of CIMMYT wheat breeding

The breeding programs of CIMMYT for bread wheat, durum wheat, and triticale were globalized to serve all agroecological regions of developing world. Fourteen agroecological regions in world were identified (Rajaram et al. 1984), later to be amalgamated into 12 mega-environments (MEs) (Rajaram et al. 1993).

Major initiatives and advances during this period have included the following:

- A project on wheat for warmer nontraditional environments supported by the United Nations Development Programme (UNDP) was initiated in 1982 to expand the adaptability and feasibility of growing wheat into these harsh environments, situated between 23° N and 23° S latitudes at altitudes below 1000 masl.
- In the early 1980s, CIMMYT began a systematic drought breeding program with extensive use of the Huamantla and Yaqui Valley sites in Mexico as moisture stress environments combined with the testing of advanced lines under a line source irrigation system.
- A Winter Wheat Breeding Program was initiated in 1985 in Turkey, as a joint venture between CIMMYT, the national program of Turkey, and the International Center for Agricultural Research in the Dry Areas (ICARDA).
- A massive breeding program was started in 1985 to introgress Karnal bunt resistance into high yielding ME1 germplasm.
- Chinese germplasm of diverse origin (10 agroecological regions) began to be introgressed into CIMMYT base germplasm to further expand the genetic variability. Initiated in 1984, this effort is a continuing joint venture between the Academies of Jiangsu (Nanjing), Sichuan (Chengdu), and Heilongjiang (Harbin), CAAS (Beijing), Henan (Zhenghou), and CIMMYT. Head scab tolerance is emphasized in this cooperative program.
- Initiatives were taken to implement effective breeding/testing programs for tolerance to drought, heat, cold, sprouting, boron toxicity (Turkey), and the cereal cyst nematode (Turkey); resistance to stripe rust and helminthosporium leaf blotch; and improved N and P utilization efficiency. All of these programs were carried out in the bread wheat program and some in the durum wheat and triticale programs as well.
- CIMMYT and ICARDA management agreed to facilitate a joint germplasm improvement undertaking in 1989 to serve the wheat germplasm needs of WANA (Western Asia and North Africa).

- Since 1977, semidwarf wheat varieties have continued to replace original tall or landrace varieties at the rate of 2 million hectares/year.
- Exploitation of the spring x winter gene pool, initiated in the second phase, has resulted in higher yield potential gains (Veery, Kauz, Attila) in the bread wheats.
- The durum wheat program has made higher yield potential gains through restructuring of the plant morphology (erect, thick stem and leaf).
- Triticales were given a semidwarf stature with a higher biomass and longer fertile spike. This resulted in higher yields.
- Stability of performance, yield potential, and disease resistance of these three species are similar; however, durum wheat and triticales are adapted to a reduced number of MEs.

Resource Allocations

Personnel

Germplasm improvement activities are described below (for more details, please see the GI Project Updates for 1993 (Fischer and Hettel 1993). The current GI staff deployment (Table 1.1) appears to be adequate, except in winter wheat (Turkey) and International Nurseries (Mexico). No breeder is posted in the Indian Subcontinent or in China, but this does not appear to be limiting as there is good interaction between CIMMYT-based scientists and national programs in these regions through visits and joint projects.

Mid-career fellowship, visiting scientist, and postdoctoral positions have declined by 50% in recent years due to a lack of resources. If additional funds become available in the future, we hope to increase these activities.

Table 1.1. Staff, support staff, and nature of funding in germplasm improvement.

Location	Activities/ Commodity	International Staff	Associate Scientists/ Postdocs	Support Staff	Nature of Funding
Mexico	BW	2	2	15	Core
Mexico	DW/TCL	1	1	14	Core
Mexico	Training	1	-	3	Core
Mexico	Int. Nurseries	-	-	7	Core
Mexico	Industrial Quality	1	-	5	Core
Mexico, Total		**5**	**3**	**44**	
Southern Cone (Montevideo)	Spring wheat	1	-	-	Core+SP
WANA/E. Europe (Ankara)	Winter wheat	1	-	4	Core
WANA (Aleppo)	Spring wheat	2	-	4	Core
East Africa (Addis Ababa)	Spring wheat	1	-	-	SP
Southern Africa (Harare)	Spring wheat	1	-	-	SP
Outreach, Total		6	-	8	
Wheat Program, Grand Total		**11**	**3**	**52**	

SP = Special Project.

Objectives

No. 1— Production of superior high-yielding and stable, widely adapted germplasm tailored to distinct MEs and distributed through formalized International Nurseries. Fifteen hundred sets of International Yield Trials and Screening Nurseries, consisting of ±4000 advanced lines of bread wheat, durum wheat, and triticale, are annually sent to more than 200 locations around the world, encompassing the 12 MEs. Distribution of ample genetic diversity is the norm: the international trial system guarantees widespread dissemination of diverse germplasm and thus provides insurance against genetic vulnerability. More than 1000 varieties of bread wheat, durum wheat, and triticale, originating directly from CIMMYT crosses or from national program crosses using a CIMMYT parent, now occupy 40 million hectares in the developing world (Byerlee and Moya 1993).

Sixty percent of the GI Subprogram's resources are allocated to this major objective. A further breakdown of this allocation involves:

- 40% for yield, yield stability, and quality-related activities.
- 40% for breeding for durable disease resistance and genetic diversity.
- 20% for breeding for tolerance to abiotic stresses (drought, heat, cold, waterlogging, salinity, aluminum, and boron toxicity and utilization of N and P.

No. 2— Human resource development through in-service training and visiting scientist programs. We plan to update and diversify the level of training in the future. Over the past 27 years, more than 400 scientists have been trained, mainly from developing countries. Ten percent of GI resources are directed towards this activity.

No. 3— Production of special genetic stocks of bread wheat, durum wheat, and triticale in relation to resistance to the rusts, septorias, BYDV, fusarium, bacteria, helminthosporium, drought, heat, cold, waterlogging, and aluminum and boron toxicity and efficient utilization of N and P. Ten percent of GI resources are used for this activity.

No. 4— Developing applied breeding methodologies and strategic research and genetic analysis. Five percent of GI resources are allocated to these activities.

No. 5— Consultation with national programs. Fifteen percent of GI resources are used in this crucial extension activity.

Shuttle Breeding and International Multilocation Testing

These two core activities enhance stability of performance and avoid genetic vulnerability. Since 1944, segregating populations have been shuttled between two environmentally contrasting locations in Mexico (Figure 1.1): Cd. Obregón, Sonora, and Toluca, Mexico.

Obregón is situated at 27.5°N and 40 masl with plenty of sunshine hours. Wheat is grown under irrigated conditions and without major disease problems except for some leaf rust and stem rust. At Obregón, planting is done in November/December when the day length is relatively short and the

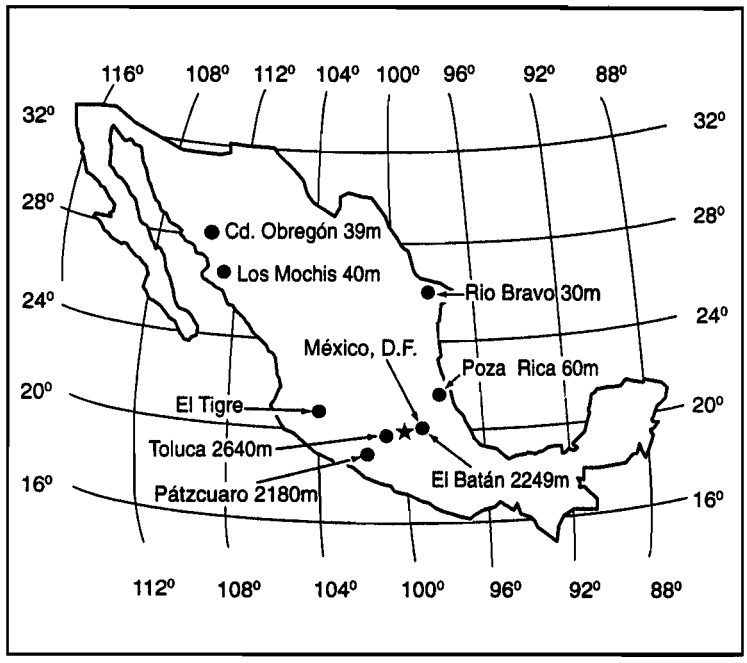


Figure 1.1. Locations and elevations of Cd. Obregón, Toluca, and other experiment stations in Mexico where CIMMYT conducts research.

average temperature is rather low. Wheat matures in April/May when day length is getting longer and temperatures are warmer. The environmental conditions are considered optimum for wheat production and provide the opportunity for maximum expression of biomass and yield if the crop is managed well. On the station, the best genotypes have yielded up to 10 t/ha—8 to 9 t/ha are not uncommon. In recent years, mean farmer yields in the area have reached 5.0 t/ha.

Toluca is situated in the high-rainfall highlands of Mexico at 18°N and 2640 masl; 1000 mm of annual rainfall mostly occur during the wheat growing season. This location is a natural disease hot spot for stripe rust, septoria leaf blotch (*Septoria tritici*), BYDV, fusarium head blight, bacteria (*Xanthomonas campestris* pv. *undulosa*) and tan spot (*Pyrenophora tritici-repentis*). At Toluca, planting is done in May/June when the day length is becoming longer as temperatures increase. Harvesting is carried out in October when the day length is shortening and temperatures are cool. The location is relatively high yielding when diseases are genetically or chemically controlled. Experimental yields up to 7 t/ha have been registered.

The seven-cycle scheme outlined below shows how germplasm is shuttled between the two locations. Depending on the location or where the cross is made, the cycle starts with the F1 in either Cd. Obregón or in Toluca. The example below uses the F1 in Cd. Obregón as the starting point:

F1: Cd. Obregón (simple cross, limited backcross). Visual selection for vigor and rust resistance.

F2: Toluca ± 2000 plants/cross are space-planted. Selected individually under high multiple disease pressure and for agronomic type.

F3: Cd. Obregón. Dense planting. Visually selected using modified bulk/pedigree methodology for rust resistance, biomass, spike density, grain plumpness, etc.

F4: Toluca. Dense planting. Visually selected using modified bulk/pedigree methodology for biomass, multiple disease resistance, grain plumpness, etc.

F5: Cd. Obregón. Same as F3 or F4.

F6: Toluca. Individual head or plant selection under multiple disease pressure.

F7: Cd. Obregón. Discarding of unwanted lines. Bulk-harvesting of selected lines.

Following bulking of the final segregating generation, the selected entries enter into the yield trial phase with the following sequence:

- Preliminary Yield Trial (PYT).
- Yield trial (YT).
- Seed multiplication
- International Screening Nursery or Yield Trial
- Analysis of international data and selection of parental stocks.

This methodology is used for bread wheat and durum wheat, but is slightly different for triticale due to its genomic instability in the early generations. The methodology has permitted the pyramiding of a large number of multiple resistance genes for use against a wide spectrum of diseases within each mega-environment. This, in part, explains the high degree of stability of performance of CIMMYT germplasm in international environments. Throughout the entire F2-F7 shuttle process, due importance is given to disease resistance, agronomic traits (height, lodging, maturity), yield characters (biomass, vigor, tillering, spike density, grain plumpness, etc.), and quality traits.

After one or two cycles of yield trials in Mexico, a final evaluation of disease resistance, and full-scale quality testing, the best advanced lines may qualify to enter into one of the ME-oriented International Screening Nurseries. The International Nursery System is ME-based and disseminated to national programs only on a request basis. An individual advanced line can be subjected to international multilocation tests in 30 to 150 locations within a particular ME. National programs and CIMMYT outreach breeders play an important role in germplasm evaluation and dissemination of data to the CIMMYT base for analysis. The best performing lines are further selected for recombination in the crossing program. This "ritual", which has been repeated now for the last 27 years (equal to 54 breeding cycles), has built genetic diversity based on cycling and incorporation of the best performers, identified and confirmed in a global setting. This successful breeding enterprise is a truly joint venture between the cooperating national programs and CIMMYT—and it could not be otherwise.

Targeted Breeding Mega-environments (MEs)

With the Strategic Plan of 1988, the CIMMYT Wheat Program reorganized and amalgamated the former 14 agroecological zones into 12 individually defined MEs. These 12 MEs constitute roughly 200 million hectares of global wheat area of which 100 million lie in the developing world.

A mega-environment is defined as a broad, not necessarily contiguous area, occurring in more than one country and frequently transcontinental, defined by similar biotic and abiotic stresses, cropping-system requirements, consumer preferences, and, for convenience, by a volume of production. Germplasm generated for a given ME is useful throughout it, accommodating major stresses, but perhaps not all the significant secondary stresses.

Thus, within an ME, we address millions of hectares with a certain degree of homogeneity as it relates to wheat, while leaving responsibility and attention for agroecological domains at the microlevel within the ME directly up to the respective National Crop Improvement Programs.

By 1993, 12 MEs involving spring wheats (ME1-ME6), facultative wheats (ME7-ME9), and winter wheats (ME10-ME12) had been defined. These are described below, listing the general area, one or more typical locations, the major prevalent diseases, and the common abiotic stresses. Spring wheats cover almost 80 million hectares in the developing countries, and facultative and winter wheats almost 25 million hectares.

Spring wheat mega-environments

ME1: Irrigated, temperate; 32 million ha; 99% bread wheat (BW).
Optimally irrigated, low rainfall areas. The climate during the growing period ranges from temperate in winter to conditions of late heat stress in more continental regions.
Area: Primarily in Asia, Africa, and Mexico.
Typical: Cd. Obregón, Mexico; Ludhiana, India.

There are four major sub-MEs:
ME1FE: Optimum environment: Only rust may be a serious problem.
ME1KB: Karnal bunt (*Tilletia indica*) is present.
ME1HT: (Late) Heat occurs during the grain-filling stage.
ME1SL: Soil/water salinity hinders growth.

ME2: High rainfall; 10 million ha; 75% BW.
Temperate environment with an average of more than 500 mm of rainfall during the cropping cycle.
Area: Concentrated in West Asia and North Africa (WANA), the highlands of East Africa, and Central America, plus the Southern Cone and Andean Highlands of South America.
Typical: Toluca, Mexico; Sevilla, Spain.
Diseases: Rusts, septorias, fusarium, BYDV.

ME3: Acid soils; 1.7 million ha; 100% BW.
Soils have pH < 5.5. Temperate environment with an average of more than 500 mm of rainfall during the cropping cycle.
Area: Mostly in Brazil, the Himalayas, and Central Africa.
Typical: Cruz Alta, Brazil.
Diseases: Rusts, septorias, fusarium, BYDV.
Abiotic: Unavailability of phosphorus, and toxic levels of aluminum and manganese are major constraints.

ME4: Low rainfall; 21.6 million ha; 67% BW.
Less than 500 mm of water are available for the crop. There are three major sub-MEs:

ME4A: 10 million ha; 53% BW.
Winter rain followed by late, Mediterranean-type drought.
Typical: Aleppo, Syria.
Abiotic: Post flowering moisture and heat stress.

ME4B: 5.8 million ha; 100% BW. Early, winter drought followed by late summer rain.
Typical: Marcos Juarez, Argentina. Mostly in Southern Cone.
Abiotic: Predominantly preflowering water stress.

ME4C: 5.8 million ha; 74% BW.
Crop growth depends largely on soil-stored moisture after monsoon rains.
Typical: Dharwar, India.
Abiotic: Water stress throughout cycle, increasing toward end.

ME5: High temperature; 7.1 million ha; 100% BW. Mean temperature of the coolest month is > 17.5°C.
Area: Primarily located between 23°N and 23°S, below 1000 masl.
There are two major sub-MEs:

ME5A: Humid environment; 3.9 million ha.
Typical: Joydebpur, Bangladesh.
Diseases: Several and severe.

ME5B: Dry environment; 3.2 million ha
Area: Semi-arid regions, where all wheat is irrigated.
Typical: Wad Medani, Sudan.
Diseases: Almost nonexistent.

ME6: High latitude; 5.4 million ha; 100% BW. Spring-planted, where winters are too severe for plant survival; January mean temperature <-10°C).
Area: Certain regions above 42°N in Northeast Asia. About 20 million ha in the former USSR are also in ME6.
Typical: Harbin, China.

Facultative wheat mega-environments

ME7: Optimum environment, irrigated. Precipitation during the growing season is lacking.
Area: Facultative Region I of China.
Typical: Zhenzhou, Anyang in Henan Province.
Diseases: Stripe rust, leaf rust, powdery mildew.
Abiotic: Moderate cold.

ME8: High rainfall. More than 500 mm of rainfall during the cropping cycle. There are two major sub-MEs:

ME8A: photoperiod-sensitive.
Area: Southern Chile; Western Pacific NW, USA.
Typical: Temuco, Chile; Corvallis, Oregon, USA
Diseases: Stripe rust, leaf rust, septoria, powdery mildew, fusarium, root rots.
Abiotic: Moderate cold, waterlogging.

ME8B: photoperiod neutral.
Area: Thrace, SE Europe, SE USA.
Typical: Edirne, Turkey.
Diseases: Stripe and leaf rust, powdery mildew, fusarium, root rot, Sunni pest.
Abiotic: Moderate cold, waterlogging.

ME9: Semi-arid. Less than 500 mm of water are available for the crop.
Area: Mediterranean Europe; transitional altitudes in West Asia and North Africa (WANA); Atlas Mountains, Morocco; southern Argentina; South Africa; Southern Great Plains, USA.
Typical: Eskisehir and Diyarbakir, Turkey; Tehran, Iran; Balochistan, Pakistan.
Diseases: Bunts, smuts, saw fly, Hessian fly, Sunni pest, Yellow rust.
Abiotic: Moderate cold, frost, drouth, heat, micronutrient deficiencies and/or toxicities.

Winter wheat mega-environments

ME10: Optimum environment, irrigated.
Area: Winter wheat Region II of China.
Typical: Beijing, China.
Diseases: Rusts, powdery mildew, BYDV.
Abiotic: Cold, rapid grain-fill required.

ME11: High rainfall. More than 500 mm of rainfall during the cropping cycle. There are two major sub-MEs:

ME11A: photoperiod-sensitive.
Area: NW Europe, Eastern USA.
Typical: Cambridge, UK.
Diseases: Stripe rust, leaf rust, powdery mildew, septorias, fusarium, eyespot, BYDV.
Abiotic: Cold, waterlogging.

ME11B: photoperiod neutral.
Area: Eastern Europe, Russia, Ukraine, Midwest USA.
Typical: Martonvasar, Hungary; Lovrin, Romania.
Diseases: Stripe rust, leaf rust, powdery mildew, septorias, fusarium, BYDV.
Abiotic: Cold winter.

ME12: Semi-arid. Less than 500 mm of water are available for the crop.
Area: Northern Great Plains, USA; Central Plateau, Turkey; Iran; Afghanistan; Russia; Eastern Europe.
Typical: Kansas, USA; Eskisehir and Konya, Turkey; Tabriz, Iran.
Diseases: Stripe rust, leaf rust, stem rust, soil pathogens.
Abiotics: Cold, drought, terminal heat, micronutrient deficiencies and/or toxicities.

Table 1.2 indicates the relative importance of bread wheat, durum wheat, and triticale in relation to the MEs for which CIMMYT conducts breeding programs. The most resources are allocated to ME1, followed by MEs2, 4, 9, and 12.

Table 1.2. Mega-environments as related to spring bread wheat, facultative/winter bread wheat, durum wheat, and triticale.

Mega-environments		Bread Wheat Spring	Bread Wheat Facult/winter[1]	Durum Wheat Spring[2]	Triticale Spring[2]
Spring					
ME1	Irrigated	*		*	*
ME2	High Rainfall	*		*	*
ME3	Acid Soils	*			*
ME4	Semi-Arid[2]	*		*	*
ME5	Tropical	*			
ME6	High Latitude	*			
Facultative					
ME7	Irrigated		*		
ME8	High Rainfall		*		*
ME9	Semi-Arid[2]		*		
Winter					
ME10	Irrigated				
ME11	High Rainfall				
ME12	Semi-Arid[1]		*		

[1] Program mainly based in Turkey; some in Mexico.
[2] Programs mainly based in Mexico; some in Syria.

References

Borlaug, N.E. 1968. Wheat breeding and its impact on world food supply. In pages 1-36, K.W. Finley and K.W. Shephard, eds., Proceedings 3rd. Int. Wheat Genetics Symp. Canberra, Australia.

Byerlee, D., and P. Moya. 1993. Impacts of International Wheat Breeding Research in the Developing World, 1966-90. Mexico, D.F.: CIMMYT.

Fischer, R.A., and G.P Hettel, eds. 1993. Research Projects Updates and Descriptions of New Projects for the CIMMYT Wheat Program. Mexico, D.F. CIMMYT. 356 pages

Hoogendoorn J., W.H. Pfeiffer, S. Rajaram, and M.D. Gale. 1988. Adaptive aspects of dwarfing genes in CIMMYT germplasm. p. 1093-1100. In: Proceedings 7th International Wheat Genetics Symposium, 1988. Cambridge.

Rajaram, S, B. Skovmand, and B.C. Curtis. 1984. Philosophy and methodology of an international wheat breeding program. In pages 33-60, J.P. Gustafson, ed., Gene Manipulation in Plant Improvement.

Rajaram, S., R.P. Singh, and E. Torres. 1988. Current CIMMYT approaches in breeding wheat for rust resistance. In pages 101-118, Breeding Strategies for Resistance to the Rusts of Wheat. Mexico, D.F.: CIMMYT.

Rajaram, S., M. van Ginkel, and R.A. Fischer. 1993. CIMMYT's Wheat breeding mega-environments (ME) In: Proceedings 8th Int. Wheat Genetics Symp. Beijing, China (in press).

Chapter 2.

Yield Stability and Avoiding Genetic Vulnerability in Bread Wheat

Sanjaya Rajaram

Introduction

Of the total bread wheat area in developing countries, estimated to be 63.1 million hectares if China is excluded, 36 million hectares or 58% are planted to varieties derived directly or indirectly from CIMMYT germplasm. The semidwarf bread wheat cultivars that launched the Green Revolution of the 1960s and 1970s doubled to quadrupled production in countries such as India, Pakistan, Bangladesh, Turkey, Mexico, and Zimbabwe. In the 1980s and 1990s, yield potential has continued to rise (Tables 2.1 and 2.2). Although agronomic factors, such as soil and water management also influence the stability of wheat production and productivity, genetic factors, such as resistances to diseases and insects and tolerances to abiotic stresses are critically important to maintaining stability of high yield in a given environment.

Table 2.1. Yields for the historical series of bread wheats for year 1990-1993, Cd. Obregón, Sonora, Mexico.

Variety	Year of Release (kg/ha)	Average Grain Yield 1990-1993 (kg/ha)		Average Biomass Yield 1990-1993		Harvest Index (%)	
Pitic 62	1962	6260±273	E	17337±889	BC	0.360	D
Siete Cerros 66	1966	6414±390	DE	17331±1047	BC	0.370	CD
Yecora 70	1970	6982±608	CD	15656±1387	D	0.446	A
Nacozari 76	1976	7035±420	BCD	18211±730	AB	0.386	CD
Ciano 79	1979	7329±478	ABC	18917±1008	A	0.387	C
Seri 82	1982	7400±334	ABC	16729±905	CD	0.442	A
Oasis* 88	1986	7656±540	AB	16434±1625	CD	0.466	A
Super Kauz 88	1988	7729±370	A	18583±970	AB	0.416	B

Source: Ken Sayre, CIMMYT (1993) in Rees et al. 1993. 0.9% genetic gain per year or 56 kg/ha/year.

Table 2.2. Yields for the historical series of bread wheat in 1993 (Cd. Obregón, Sonora, Mexico).

Variety	Year of Rel.	Average Grain Yield (kg/ha)		Average Biomass Yield (kg/ha)		Harvest Index (%)	
Pitic 62	1962	6770±479	DE	18905±999	AB	0.357	CD
Siete Cerros 66	1966	6613±368	E	18642±989	AB	0.356	CD
Yecora 70	1970	7504±218	BCD	17619±358	BC	0.427	AB
Nacozari 76	1976	6536±200	E	18814±647	AB	0.348	D
Ciano 79	1979	7858±458	ABC	20438±774	A	0.384	C
Seri 82	1982	7152±195	CDE	15852±374	C	0.451	A
Oasis* 88	1986	8196±230	AB	18060±680	B	0.455	A
Super Kauz 88	1988	8545±106	A	20318±91	A	0.419	B

Source: Ken Sayre, CIMMYT (1993) in Rees et al. 1993. 1.0% genetic gain per year or 68 kg/ha/year.

Almost 100 years ago in Australia, Farrer (1898) recognized the importance of general resistance to rust in wheat. This resistance was apparently of the slow rusting type, as described by Caldwell (1968). Nevertheless, with the early discovery of physiological specialization in rust by Stakman et al. (1962), and the clarification of the genetic basis of resistance (Biffen 1905, Flor 1956), the scientific plant breeding community predominantly focused its attention on the hypersensitive (specific) type of resistance for crop protection until the early 1960s. This approach appeared to be very attractive from the crop cleanliness point of view.

The phenomenon of single gene erosion led various scientists to look for alternative methods of gene deployment and management. Broad-based resistance to stem rust proposed by Watson and Luig (1963) and the multilineal approach promoted by Jensen (1952) and Borlaug (1953) were models of resistance breeding that evolved out of the frustration associated with the frequent failures of single-gene hypersensitive resistance. Van der Plank (1963) was the first epidemiologist to define clearly the theoretical basis of the concepts of resistance. In the late 1960s and throughout the 1970s, there was a revival of the concept of general (nonspecific) resistance and its application in crop breeding (Caldwell 1968, Nelson 1978).

Three well recognized authorities in crop breeding in the 1960s, disillusioned due to the recurring failures of hypersensitive resistance, committed themselves fully to breeding for general resistance of the type recognized by Farrer in 1898. They were J.S. Niederhauser of the Rockefeller Foundation in Mexico, who was breeding field resistance to the late blight fungus in potato in Toluca (Mexico); N.E. Borlaug also of the Rockefeller Foundation in Mexico, who was breeding general resistance to stem rust of wheat; and R.M. Caldwell of Purdue University, who was breeding slow leaf rusting varieties of wheat. Niederhauser et al. (1954), Borlaug (1966, 1972), and Caldwell (1968) were proponents of the application of general resistance in breeding and conducted applied breeding that introduced general resistance into their respective crop varieties.

Over the last 30 years, scientists have used a confusing number of terminologies to describe different concepts of resistance. During the same period, CIMMYT bread wheat breeders launched concentrated efforts on applying slow rusting to leaf rust as defined by Caldwell (1968). Earlier (1950-1970), CIMMYT and its predecessor organization, led by Borlaug and counseled by Prof. E.C. Stakman of the University of Minnesota, spearheaded the broad-scale application of the now widely acclaimed durable resistance to stem rust that originated from the variety Hope (Knott 1968, McFadden 1930). This resistance source has been popularly described in CIMMYT literature as the *Sr2*-complex (Rajaram et al. 1988).

CIMMYT's Strategy for Durability of Resistance

Breeding general resistance of a partial nature (slow rusting) based on historically proven stable or durable genes

This nonspecific resistance can be further diversified by accumulating several minor genes (of which we believe there are many), and combining them with different specific genes to provide a certain degree of additional genetic diversity. This describes the basic theoretical concept for resistance breeding at CIMMYT, be it for rusts, septoria leaf blotch, helminthosporium spot blotch, fusarium head scab, etc. (Figure 2.1).

Based on studies conducted at CIMMYT (Huerta 1985, Singh et al. 1991), the features of general resistance to leaf rust in CIMMYT germplasm have been determined as follows:

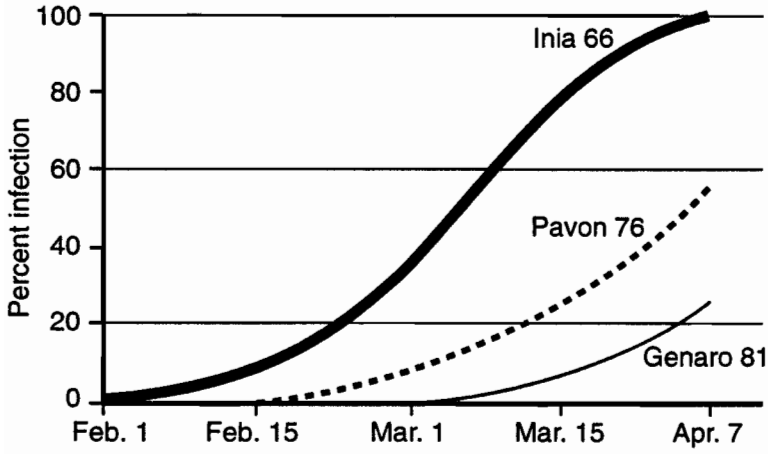


Figure 2.1. Slow rusting resistance of Genaro 81 and Pavon 76 to leaf rust when compared to Inia 66 (Cd. Obregón 1984-85).

- Expression of resistance as a longer latency period, lower receptivity, and smaller uredial size with high associations among these three characteristics.
- When only one or two minor genes operate, phenotypically low, partial resistance effects are seen, which are highly influenced by the environment and inoculum load. This type of resistance is less acceptable because in some disease-prone years, high disease levels may be observed.
- When three to four minor additive genes operate, phenotypically high partial resistance effects are observed, which show stable performance under most environments and under high inoculum loads. This resistance is more acceptable because only low disease levels are noted under most epidemics.

Genetic diversity

Since wheats derived from CIMMYT materials are grown on a large area and are exposed to a variety of pathogens under conditions that may favor disease development, our breeding strategy has been to utilize sources of germplasm that are as diverse as possible for resistance to rusts and other diseases.

The sources of resistance in CIMMYT germplasm have, by intent, been kept very diverse, through the constant influx of new germplasm and its use in the crossing program. The value of such diversity was recently shown in Australia. When yellow rust was introduced there in the early 1980s, most of the locally developed varieties without CIMMYT germplasm in their pedigree were highly susceptible, but CIMMYT-derived germplasm was shown to be highly resistant (R.A. McIntosh, per. comm.). As a result, Australian plant breeders began to use CIMMYT germplasm as a principal source of yellow rust resistance in their breeding programs.

Status of Disease Resistance in CIMMYT Bread Wheat Germplasm

Major pathogens at the mega-environment level (> 5 million hectares)

Stem rust (*Puccinia graminis* f.sp. *tritici*)—There has been global stability after 40 years of utilization of the genes from the variety Hope. While this resistance is dubbed the *Sr2*-complex in popular CIMMYT literature, it actually consists of *Sr2* plus eight to ten genes pyramided in three- to four-gene combinations. *Sr2* itself is commonly present in most CIMMYT germplasm and serves as the "backbone" gene. Alone, it behaves as a slow ruster. Historical data sufficiently support this gene complex to indicate an impressive level of durability of resistance.

Leaf rust (*Puccinia recondita* f.sp. *tritici*)—A high degree of stability of performance is based on the genes derived from the Brazilian variety Frontana. Four partial resistance genes, including *Lr34*, giving a slow rusting response, have been responsible for the containment of leaf rust epidemics on a global scale for the last 15 years. Sixty percent of the CIMMYT germplasm carries one to four of these partial

resistance genes and, since being widely deployed, no major epidemic has been reported on a worldwide level—a major achievement in modern wheat breeding. The challenge is to identify more genetic variability of the partial resistance type found in Frontana. If found, this variability needs to be quantified and pyramided into the existing high-yielding germplasm.

Stripe rust (*Puccinia striiformis*)—Slow rusting genes have been identified; however, their interactions are less additive than for stem rust and leaf rust. More basic work on CIMMYT germplasm is needed to understand the status of the durable resistance base in high-yielding wheats. High-yielding varieties have succumbed to new races after their release, indicating the presence of hypersensitive genes. The challenge is to ensure the presence of several effective slow rusting genes across a vast spectrum of CIMMYT germplasm.

Septoria leaf blotch (*Septoria tritici*)—This disease was a major challenge for germplasm improvement in the early 1970s, as all semidwarfs, developed for irrigated production, were shown to be susceptible. More than eight genes have been identified and two to three genes in combination provide good partial resistance. High levels of resistance have been combined with high yield potential and good thousand kernel weight. The future breeding challenge lies in pyramiding of the above-mentioned genes and to spread them more widely throughout high-yielding backgrounds.

Karnal bunt (*Tilletia indica*)—The spread of resistant varieties across the vast areas of ME1, where disease is a problem, is still lacking. More than five genes (partial resistance) have been identified, used in breeding, and now available in high yielding backgrounds. We now await release and adoption by affected national programs.

Powdery mildew (*Erysiphe graminis* f.sp. *tritici*)—The genetic base in CIMMYT germplasm is not precisely known. A few years ago, a new race of powdery mildew devastated CIMMYT germplasm in Southern Cone countries of South America. Since then, we have considered our germplasm vulnerable to the pathogen. The major responsibility for identification, quantification, and transfer of durable resistance to powdery mildew has been delegated to the regional CIMMYT breeder in South America because the disease is absent in Mexico.

Loose smut (*Ustilago tritici*)—Chemical control is accepted and employed in most MEs. Genetic resistance is available, but needs to be exploited.

Minor pathogens at macro/micro-environment level (< 5 million hectares)
Barley yellow dwarf virus (BYDV)—Two tolerance genes have been identified and are present in 60% of CIMMYT germplasm. The tolerance is of a partial nature and has been effective at least 35 years. Alien sources of genetic resistance/tolerance are being awaited from intergeneric crosses.

Septoria glume blotch (*Septoria nodorum*)—The genetic basis of resistance has not been studied in CIMMYT germplasm. However, a satisfactory level of resistance appears to exist in the germplasm.

Spot blotch (*Bipolaris sorokiniana*)—A partial level of resistance has been derived from Chinese germplasm and from wide crosses. Genetic studies are in progress to reveal the genetic variability available.

Tan spot (*Pyrenophora tritici-repentis*)—An acceptable amount of germplasm is resistant to moderately resistant.

Bacteria (*Xantomonas campestris* pv. *undulosa*)—Three resistance genes have been clearly identified. They appear widely scattered throughout the germplasm base. The genes appear to be hypersensitive, but nonetheless, so far durable.

Scab (*Fusarium* spp.)—Most CIMMYT lines are susceptible. Attempts are being made to transfer resistance found in Chinese materials to CIMMYT germplasm.

Russian wheat aphid (*Diuraphis noxia*)—The germplasm is generally vulnerable. Attempts will be expanded to transfer genes for resistance, now available from the CIMMYT germplasm bank.

Hessian fly (*Mayetiola destructor*)—Some resistance has been reported, but high yielding varieties until now have lacked sufficient resistance. Major responsibility has been given to the CIMMYT/ICARDA joint effort for combining effective resistance with stable high yields.

Sawfly (*Cephus cinctus*)—Morphological resistance, based on solidness of the plant stem, is available.

References

Biffen, R.H. 1905. Mendel's laws of inheritance and wheat breeding. J. Agric. Sci. 1:4-48.

Borlaug, N.E. 1953. New approaches to the breeding of wheat varieties resistant to *Puccinia graminis tritici*. Phytopathology 43:467 (Abstract).

Borlaug, N.E. 1966. Basic concepts which influence the choice of methods for use in breeding for disease resistance in cross pollinated and self pollinated crop plants. In pages 327-348, H.D. Gerhold et al., eds., Breeding Pest Resistant Trees. Pergamon Press, Oxford.

Borlaug, N.E. 1972. A cereal breeder and exforester's evaluation of the progress and problems involved in breeding rust resistant forest trees. In pages 542-615, Biology of Rust Resistance in Forest Trees. Proc. of a NATO INFRO Advanced Study Institute. Aug. 17-24, 1969, USDA Forest Service, Misc. Publ. 1221.

Caldwell, R.M. 1968. Breeding for general and/or specific plant disease resistance. In pages 263-272, Proc. 3rd Int. Wheat Genetics Symp. Canberra, Australia.

Farrer, W. 1898. The making and improvement of wheats for Australian conditions. Agr. Gaz. N.S. Wales 9:131-168.

Flor, H.H. 1956. The complementary genic in flax and flax rust. Adv. Genet. 8:29-54.

Huerta, J.E. 1985. Resistencia de patogenia lenta a roya de la hoja (*Puccinia recondita* f.sp. *tritici*. E. y H.) en trigo. Ms. Thesis. Colegio de Postgraduados, Chapingo, Mexico.

Jensen, N.F. 1952. Intervarietal diversification in oat breeding. Agron J. 44:30-34.

Knott, D.R. 1968. The inheritance of resistance to stem rust races 56 and 15B-IL (Can.) in the wheat varieties Hope and H-44. Can. J. Genet. Cytol. 10:311-320.

McFadden, E.S. 1930. A successful transfer of emmer characters to vulgare wheat. J. Amer. Soc. Agron. 1020-1034.

Nelson, R.R. 1978. Genetics of horizontal resistance to plant disease. Ann. Rev. Phytopath. 16:359-378.

Niederhauser, J.S., J. Cervantes, and L. Servin. 1954. Late blight in Mexico and its implication. Phytopathology 44:406-408.

Rajaram, S., R.P. Singh, and E. Torres. 1988. Current CIMMYT approaches in breeding wheat for rust resistance. In pages, 101-118, S. Rajaram and N.W. Simmonds, eds., Breeding Strategies for Resistance to the Rusts of Wheat. CIMMYT, Mexico.

Rees, D., K. Sayre, E. Acevedo, T. Nava Sánchez, Z. Lu, E. Zeiger, and A. Limón. 1993. Canopy Temperatures of Wheat: Relationship with Yield and Potential as a Technique for Early Generation Selection. Wheat Special Report No. 10. Mexico D.F.: CIMMYT.

Singh, R.P., T.S. Payne, and S. Rajaram. 1991. Characterization of variability and relationship among components of partial resistance to leaf rust in CIMMYT bread wheats. Theor. Appl. Genet. 82:674-680.

Stakman, E.C., D.M. Stewart, and W.Q. Loegering. 1962. Identification of physiologic races of *Puccinia graminis* var. *tritici*. USDA-ARS E-617 (Rev.). 53 p.

Watson, I.A., and N.H. Luig. 1963. The classification of *Puccinia graminis* var. *tritici* in relation to breeding resistant varieties. Proc. Linn. Soc. N.S.W. 88:235-258.

Van Der Plank, J.E. 1963. Plant Diseases: Epidemics and Control. Academic Press, New York and London.

Chapter 3.

Expanding the Genetic Base of CIMMYT Bread Wheat Germplasm

Reynaldo L. Villareal

Introduction

Broad-based plant germplasm resources are imperative for sound and successful crop improvement programs. Rich and diverse sources also fuel many facets of plant research. The genetic diversity of experimental materials needs to be sustained to minimize the vulnerability inherent in the growing of uniform and closely related cultivars over wide areas. Genetic diversity becomes more important as cropping intensity and monoculture continue to increase in all major wheat-producing regions of the world. The alarming reduction of genetic diversity and the consequent increase in genetic vulnerability to serious disease and insect ravages have been studied and publicized in several articles, of which Genetic Vulnerability of Major Crops (National Academy of Sciences 1972) provides the most comprehensive and detailed review. Whereas uniformity within a crop leads to genetic vulnerability, reinstatement of genetic diversity is one of the most effective means of protection against such vulnerability. The study and use of genetic diversity is crucial to the continuing success of the CIMMYT Bread Wheat Program, in increasing stability in its germplasm, and meeting its objective to assist NARSs in increasing the reliability of food production.

In the past direct exchange of advanced rather than unimproved germplasm by breeders has had a most notable effect on wheat improvement. Sometimes, single collections have had dramatic impacts, e.g., the few F3 seeds of the Norin 10/Brevor cross, sent by Prof. Orville Vogel from Washington State University to Dr. Norman Borlaug in Mexico in 1953, formed the foundation of most semidwarf wheats grown in the developing world today. Several collection from Turkey, including PI178383, and from Kenya helped US breeders overcome serious bunt and rust epidemics. The use of two or three Russian winter wheats propelled yield potential due to the 1BL/1RS translocation they carried, in many modern wheats.

Rasmusson (pers. comm.), in a recent lecture at CIMMYT headquarters to young breeders from developing countries, listed "sharing germplasm" as one of the three "cornerstones of progress in plant breeding". He estimates one half of all genetic advances made are derived from sharing material between researchers. Also he believes much diversity is still hidden in elite gene pools, awaiting discovery and exploitation, without yet the urgent need to work with exotic sources of new genes. In adapted backgrounds, favorable linkage groups are better preserved. Indeed, breeders are known to be often reluctant to directly use wild relatives in their crosses for fear of introducing more undesirable than desirable genes. There lies a new area of activities for the pre-breeder.

Past Use of Introduced Diversity

In 1944, when Borlaug arrived in Mexico, he started his breeding work with the local wheat varieties. These were mixtures of many different types. Their country of origin was mostly unknown, but likely was Spain plus some introductions from the USA. Three newly acquired introductions contributed to

many of the first "Mexican" varieties; Mentana (Italy), Marroqui=Florence Aurora (Tunisia) and Gabo (Australia). By 1955 the Rht1 and Rht2 genes, originating from the Japanese variety Norin 10 introduced into the USA, were incorporated into the Mexican germplasm.

In the mid- to late-1950s, visitors to the Mexican program from Latin America started bringing seed of their own varieties to Mexico, e.g., Andes 56. By 1961, the first official group of wheat improvement trainees came to Mexico, largely from North Africa and the Middle East. These scientists took genetic material from CIMMYT back to their own countries. Thus, started a regular exchange of germplasm, in particular with former CIMMYT trainees and visitors. Through this sharing of germplasm, lines from WANA and South America were identified that contributed resistance to *Septoria tritici.*

By the late 1960s, winter and facultative wheats were solicited, particularly from Chile, the USA and Eastern Europe, with the aim to attempt the transfer of resistance genes to foliar diseases, and genes for tolerance to cold and heat, plus possibly to drought. The winter x spring crossing efforts were expanded in the early 1970s to include a cooperation with Oregon State University USA. By the late 1970s and early 1980s, many advanced lines were obtained from crosses between these two distinct gene-pools. It was subsequently established that a major contributing factor to the increased wide adaptation and stability was the 1BL/1RS translocation. The 1B/1R translocation carries a number of resistance genes, such as *Lr26, Sr31, Yr9,* and *Pm8* (McIntosch 1983).

In 1973, an official collaboration was established with Brazilian breeders in order to combine acid soil tolerance, a major requirement in Southern and Central Brazil, with high yield potential. With this collaboration many new materials were introduced from South America into Mexico. In retrospect, it could be shown that besides acid tolerance, several of these introduced varieties contributed varying levels of resistance to *Septoria tritici, S. nodorum, Helminthosporium sativum, Helminthosporium tritici-repentis, Xanthomonas campestris* pv. *undulosa,* Fusarium head scab, BYDV, and even Karnal bunt (*Tilletia indica*).

In 1988, a joint agreement on shuttle breeding was signed with the Chinese Academy of Agricultural Sciences, aimed at combining Fusarium head scab resistance with high yield potential and rust resistance. Increasingly Chinese germplasm was shared with CIMMYT, thus opening up a very new gene pool, previously inaccessible. As expected, Chinese material contained resistance to Fusarium head scab, but also resistance genes to Karnal bunt, a disease not present in China, *Septoria tritici, Xanthomonas campestris* pv. *undulosa, Helminthosporium sativum,* and *Helminthosporium tritici-repentis* were noted. Presently, about 10% of the segregating materials in the Bread Wheat Program contain Chinese lineage.

By the early 1990s, regular germplasm exchange with 80% of our cooperators had become practice. Annually 2000-3000 introductions are received from all major wheat growing areas.

New Sources of Diversity

Secale cereale

Translocations of the short arm of rye chromosome 1R to wheat are of particular interest to our breeding program. This arm has been shown to carry genes for resistance to leaf rust, stem rust, stripe rust, powdery mildew, greenbug, and wheat streak mosaic virus. From recent yield tests of F2-derived F6 lines, it can be inferred that yield genes also had been introgressed. Yield advantages of 4.3 and 4.2% have been statistically measured on 1B/1R genotypes under optimum and reduced irrigation conditions,

respectively (Tables 4.1 and 4.2). Similarly, 1A/1R genotypes yielded up to 4.4% better than the 1A homozygous lines (Del Toro et al. 1993). In addition to the 1BL/1RS and the 1AL/1RS translocations, the 5AL/5RL translocation are recently being crossed in Mexico. In a collaboration with A.J. Lukaszewski (University of California-Riverside), additional rye segments from various sources, and multiple translocation stocks, are being developed in CIMMYT backgrounds, such as the variety Pavon.

Table 4.1. The effect of 1B/1R chromosome translocation on yield characteristics of 28 F2-derived F6 lines from the cross Nacozari/Seri 82 under optimum irrigated condition during the 1991-92 and 1992-93 crop cycles at Yaqui, Sonora, Mexico.

	Wheat lines			
Plant characteristic	**With 1B/1R**	**Non-1B/1R**	**LSD (0.05)**	**CV (%)**
1000-grain weight (g)	40.19	39.87	0.37	2.87
Test weight (kg/hl)	79.8	78.8	0.2	0.95
Plant height (cm)	91.2	94.1	0.7	2.39
Spike length (cm)	9.9	10.1	0.1	4.95
Days to flowering	80.3	79.4	0.7	2.92
Grainfill period (day)	45.8	46.1	0.7	4.95
Physiological maturity (day)	126.1	125.5	0.7	1.88
Harvest index (%)	41.3	40.7	0.9	7.22
Above-ground biomass (t/ha)	15.2	14.7	0.4	9.05
Grain yield (kg/ha)	6266	6006	114	6.01
Spikes/m^2	373	377	13	11.52
Grains/m^2	15906	15634	260	5.83
Grains/spike	44.3	42.6	1.3	9.70

Table 4.2. The effect of 1B/1R chromosome translocation on yield characteristics of 28 F2-derived F6 lines from the cross Nacozari/Seri 82 under reduced irrigated condition during the 1991-92 and 1992-93 crop cycles at Yaqui, Sonora, Mexico.

	Wheat lines			
Plant characteristic	**With 1B/1R**	**Non-1B/1R**	**LSD (0.05)**	**CV (%)**
1000-grain weight (g)	37.05	36.53	0.45	4.66
Test weight (kg/hl)	78.2	77.8	0.3	1.34
Plant height (cm)	88.9	92.4	1.1	3.95
Spike length (cm)	11.1	10.9	0.2	5.12
Days to flowering	79.8	78.6	0.5	2.01
Grainfill period (day)	37.9	37.2	0.5	4.93
Physiological maturity (day)	117.6	115.8	0.7	2.06
Harvest index (%)	39.2	39.0	0.09	7.45
Above-ground biomass (t/ha)	12.6	12.1	0.4	10.44
Grain yield (kg/ha)	4945	4743	159	9.77
Spikes/m^2	329	331	16	11.85
Grains/m^2	14074	13922	209	10.04
Grains/spike	43.5	40.6	1.6	10.75

Synthetics

A recent undertaking has been the reconstitution of bread wheat, or in other words, the production of synthetic bread wheats, by crossing durum wheat to *Triticum tauschii*. The first parent contributes the A- and B-genomes, and the wild relative hopefully new diversity by way of the D-genome. The production of stable synthetics is carried out by the CIMMYT Wide Crosses Program. Substantial morpho-agronomic variation and resistance to Karnal bunt were observed among the synthetics (Villareal et al. 1991, Villareal et al. 1993). These synthetics are then used as females and crossed to adapted, non-Ne2 carrying bread wheats. Sometimes, an additional topcross to a bread wheat parent is made. Preliminary data are presented in Table 4.3. Since several hundred *T. tauschii* accessions are available that remain to be exploited, this source of diversity promises to be very rewarding.

Alien translocations

Thinopyrum curvifolium has been used by the program to enhance the resistance of bread wheats to spot blotch caused by *Helminthosporium sativum*. Results of the yield trials in Poza Rica were conclusive that several *Th. curvifolium* derivatives were superior to both the susceptible and resistant checks (Villareal et al. 1992). Some of the *Th. curvifolium*-derived lines also showed resistance to *Septoria tritici* in separate tests at Toluca. *Haynaldia villosa* translocations, originating from China, have been used in crosses as sources of resistance to Fusarium head scab, but their contribution remains to be established. Other alien sources, such as *Th. distichum, Th. scirpeum, Elymus giganteus, Th. bessarabicum,* and *Th. intermedium* are being used by colleagues in other sections of the CIMMYT Wheat Program. Their factual contribution to disease resistance and/or stress tolerance remains largely to be proven. Such alien sources may show promise, but segments or selected genes need first to be introgressed into translocation stocks before the bread wheat breeders can use them.

Triticum dicoccoides

Wild emmer wheat (*T. dicoccoides*) is receiving recent attention in crosses, but it is too early to determine its potential contribution. Traits of interest are resistances to stripe rust, leaf rust, powdery mildew, *Septoria* spp., and Wheat Streak Mosaic Virus, plus tolerance to drought, and high grain protein content. Hybridizations with European winter bread wheats proved straight forward and several advanced lines are presently in some European National Trials. Most interestingly, some gain in yield also appears to have been achieved. At the recent 8th International Wheat Genetics Symposium in Beijing, China, various authors also indicated their perception that besides resistance genes, unexploited yield genes were present in wild emmer wheat. The use of wild emmer wheats will be further evaluated.

Table 4.3. Yield and performance of four outstanding crosses of bread wheat with synthetic wheats in recent yield trials in Obregón

	Yield (t/ha)	% of check	Days to heading	1000-grain weight
Chen/*T. tauschii*/Bcn	7.74	121	95	53
Cndo/R143//Ente/Mexi/ 3/Ae.sq./4/Weaver	6.83	134	83	NA
Altar84/*T. tauschii*/Ocoroni	6.77	122	88	NA
Chen/*T. tauschii*/Turaco	6.37	112	80	NA

Durum wheat

In recent years, it has appeared possible to move some yield components from durum wheat into bread wheat, among which large seed size, resulting in improved yields. From recent preliminary yield trials at Obregón, six outstanding crosses of bread wheat with durum wheat yielded 5 to 20% better than their bread wheat check cultivars. e.g., Seri*2/Aix (6.94 t/ha); Seri *2//Gta/Dur69 (6.72 t/ha), etc. Through this route, we attempt to improve the seed size and 1000-grain weight of bread wheats. Large seed size is a much desired trait in the Indian Subcontinent, where one third of our clientele is located.

Culmination

The parental group of lines considered for crosses in any one year consists of 500-800 chosen entries. Twice a year about 30% of our active parental stocks are rejuvenated with outstanding introductions. Hence, the influx of genetic diversity of a more conventional nature into the program is sizeable and continuous. These new materials are intercrossed at a rate of about 2000 crosses per year to our "normal" stocks, out of a total of 6000 crosses made annually.

Commercial varieties grown on wide areas, of which many are often of CIMMYT descent, are used to contribute traits entailed in adaptation and stability. Also many introductions and such nonconventional sources as durum wheat, related species and grass species are sought for specific traits, such as seed size, disease resistances, and tolerances to abiotic stresses. The latter groups are often used as females, largely for logistical reasons, but also to preserve any cytoplasmic diversity which may be introduced.

All crosses are targeted towards specific mega-environments and subsequent selection is carried out with the relative adaptative traits required in mind for the respective mega-environment, e.g., phenology, straw strength, early vigor, etc., and certain other traits including resistances, tolerances, and industrial quality.

Eventually, the process after several sets of yield trials repeated over time and space, culminates in International Nurseries and International Yield Trials targeted especially towards the intended mega-environments. The resulting germplasm addresses most major requirements within the respective mega-environments. Fourteen different International Nurseries and Yield Trials emanate from the Bread Wheat Breeding Program.

The average NARS in developing countries needs to address three to four agroclimatic environments (D. Byerlee, pers. comm.). Subsequently, a NARS will likely request International Nurseries and Yield Trials covering more than one mega-environment. On average, it will receive new diversity in the form of about 600-800 new advanced lines every year.

Conclusions

The influx of introductions and hence diversity into the Bread Wheat Program is large, and in almost all cases selected introductions when crossed are used as females, thus preserving any cytoplasmic diversity which may be present. Alien sources, both from different species and genera, are being crossed to encourage recombinations and/or translocations. The resulting variety of advanced segregating materials is rarely carried along in the breeding program beyond the F7 generation, and thus contain a low percentage of inherent variability, as well in the form of heterozygosity as in heterogeneity. The international data indicate that the created variability is large, and that different NARSs will likely select very different lines from among the diversity provided. Hence a diverse input into the Bread Wheat Program results in a balanced and varied output.

References

Del Toro, E., R.L. Villareal, S. Rajaram, and A. Mujeeb-Kazi. 1993. Effect of the 1AL/1RS chromosome translocation on traits of spring wheats. Agronomy Abstracts, p. 86.

McIntosch, R.W. 1983. A catalogue of gene symbols. In pages 1197-1255, Proc. 6th IWGS, Kyoto, Japan.

National Academy of Sciences. 1972. Genetic vulnerability of major crops. National Academy of Sciences, Washington, D.C. 307 pp.

Villareal, R.L., A. Mujeeb-Kazi, S. Rajaram, and E. del Toro. 1991. *Triticum durum* x *Triticum tauschii* synthetic hexaploid wheats—new germplasm for wheat breeding. In Abstracts of the Symposium on Plant Breeding in the 1990s. North Carolina State University. Department of Crop Science Research Report No. 130. 80 pp.

Villareal, R.L., A. Mujeeb-Kazi, S. Rajaram, and L. Gilchrist. 1992. Advanced lines derived from wheat (*Triticum aestivum* L.) and *Thynopyrum curvifolium* resistant to *Helminthosporium sativum*. In page 64, Proc. First International Crop Science Congress, Iowa State University, Iowa.

Villareal, R.L., G. Fuentes-Davila, S. Rajaram, E. del Toro, and A. Mujeeb-Kazi. 1993. Screening of synthetic hexaploid wheats (2n=6x=42) for Karnal bunt (*Tilletia indica* Mitra) resistance. Agronomy Abstracts, 195-196 pp.

Chapter 4.

Bread Wheat Breeding for Yield under Drought Conditions

Maarten van Ginkel

Target Environments

From its official inception, the Bread Wheat Program has produced germplasm that has been released in dry environments. Presently, we have defined six different submega-environments in which drought plays a major role (Table 3.1).

ME4A, ME9, and ME12 are characterized by sufficient rainfall prior to anthesis followed by drought during the grain-filling period. This pattern is also called "late drought". ME4B and ME6 typically experience drought early in the season, with rainfall occurring during the grain-filling phase. Such a rainfall distribution is also known as "early drought". ME4C is that growing environment where the wheat crop utilizes the water reserves left from the monsoon rains. It is called "residual moisture" drought.

This division of drought production environments is not complete. Rainfall patterns often vary significantly in the same region from year to year.

What makes a particular drought site/cycle often so little representative of an entire drought target environment is the spatial and temporal variability within droughty environments. The potential diversity of environmental conditions is larger at lower yield levels than at higher yield levels, as was shown most interestingly by Arntzen (1986): there are more different ways of obtaining low yields than there are for achieving very high yields. Thus, any increased GxE interaction at lower yield levels as a result of the inherent increased environmental diversity will make selection at any one stress site in any one year less effective in regard to its relevance to the entire stress target environment.

Table 3.1. Submega-environments involving drought conditions (≤ 500 rainfall).

Submega-environment	Moisture regime	Temperature regime	Wheat type	Sown	Example location	Production 1984-86 (10^6 t)
ME4A	Winter dominant	Temperate	Spring	A	Morocco, Settat	10
ME4B	Summer dominant (frost risk)	Temperate	Spring	A	Argent. M. Juarez	4
ME4C	Mostly residual moisture	Hot	Spring	A	India, Dharwar	6
ME6	Summer dominant	Temperate	Spring	S	China, Harbin	13
ME9	Winter dominant	Moderate cold	Facult.	A	Turkey, Diyarbakir	4
ME12	Winter dominant	Severe cold	Winter	A	Turkey, Konia	11

A= Autumn; S= Spring.

Understanding Performance under Drought

The above described heterogeneity of the target environment makes it difficult to determine how exactly production is most affected by drought.

There are two basic philosophies regarding which environment should best be used for selection:

- Optimal conditions with water and nutrients non-limiting, guarantee the best selection efficiency, since yield potential is maximized and hence heritability and subsequent genetic gain from selection. Evaluation under drought must follow.
- Drought conditions represent the target environment, and therefore provide the relevant selection environment.

Heritabilities and Response to Selection

Heritabilities are a function of the available (additive) genetic variability, and thus of the expanse in trait expression on which selection takes place. Certain traits such as waxiness, leaf rolling, leaf firing, leaf shedding, and proline production are actually more differentially expressed under drought stress than under optimum conditions. Hence, their heritabilities and response to selection are, in fact, expected to be greater in stress environments. Bolaños and Edmeades (1993) found a typical example of increased trait differences and subsequent gain from selection under drought stress in maize, relative to nonstress. Anthesis-silking interval (ASI) in maize was negatively correlated to yield across all stress levels, but most differentially so at the higher levels of stress, thus making it a useful selection tool, especially under stress conditions.

The idea, that heritabilities are always and necessarily lower in stress conditions, is also due to the often observed fact that under stress "realized heritabilities" for the important trait, yield, tend to be lower. But these estimates of heritability also contain a GxE component, and are not a true estimation of genetic heritability.

Although heritabilities may often well be lower in stressed conditions for certain traits, including such important ones as yield, trial management can also be modified to improve the selection efficiency (Rajaram 1991). According to Parlevliet et al. (1991), the heterogeneity of soil conditions is the course for most reduced genetic gains under stress. Allen et al. (1978) have shown that increasing the numbers of replications can bring yield testing in stress environments within the realm of acceptable heritabilities. Also, somewhat larger plots corrected heritabilities upwards dramatically.

Ultimately, it is correct, however, that for the majority of traits, heritability appears to be higher in favorable environments, since the phenotypic—and hence often the (additive) genotypic—variance tends to increase proportionally with mean yield (Allen et al. 1978).

Traits

Many reports in the literature show that a multitude of specific traits contribute to improved yield under drought. However, few of these traits have been fully adopted by breeders, or have been documented to have resulted in germplasm widely adopted by farmers. Initial papers identifying traits are often not followed by subsequent publications presenting evidence of their practical contribution to

selection for performance under stress. However, no widely accepted trait has yet presented itself, which has found favor with breeders (Fischer 1981, Clarke et al. 1992).

From a distance, these developments should be followed by breeders, but at the same time, varietal development must continue. In the latter enterprise, performance of advanced lines under drought remains the final, integrated criterion of choice.

Apart from the biological difficulties in breeding for drought, there are other reasons that explain the much reduced rates of annual gain in drought breeding of about 0.5%, relative to the value of 1% under optimum conditions (CIMMYT 1989). Breeders, often entrusted with the responsibilities for several distinct target environments within their region, have tended to favor research for optimum conditions. There, absolute gains are larger and more easily observed, proven and documented. A 10% yield gain at the 6 t/ha yield level can be significantly shown. A 20% yield gain at the 1.5 t/ha level is consumed by the error term. In addition, governments have invested less in research for the more marginal areas, emphasizing rather those higher production regions, that, in more spectacular ways contribute to the national production figures, and more directly influence the living standard of (largely urban) consumers, plus, they hope, their voting behavior.

In this scenario of a largely unsuccessful pursuit of individual traits and a diminished interest by breeders and governments themselves, advances have nevertheless been made in developing "drought adapted" germplasm. How can that be explained?

One of the fundamental, contributing factors to yield in any situation is the inherent ability of a genotype to translate input into output. If a genotype more efficiently utilizes the available water, CO_2, light, etc. to produce higher yields, it is said to have a higher "yield potential". High yield potential can be visualized as an "engine" that affects an optimal conversion from environmental inputs to grain output. Such an engine is, by definition, highly responsive to inputs, highly input efficient, and hence must be finely "tuned".

Yield potential is best measured under conditions where stress of any sort is absent, such as in "maximum" yield trials. The data obtained from such trials tend to translate almost directly to similar environments. High yielding environments tend to be more uniform between years and between locations than stressed environments. There are fewer "ways" to get it right. Therefore, CIMMYT germplasm, from the early 1960s on, proved to be well adapted to such far-away, high-yielding environments as northern India, Pakistan, Zimbabwe, and Egypt.

Clearly, such an inherently efficient, internal "engine" should not only be at the core of germplasm targeted for favorable production environments, but it should logically also serve as the foundation for genotypes intended for more stressed environments, on which to build the relevant resistances and tolerances. Therefore, such high yield potential germplasm, stemming from ME1 breeding activities, is often used as the "mother" in crosses intended for more stressed mega-environments. Subsequent deductive analysis shows yield potential to have been a major contributor to yield under stress such as, for example, drought. Several studies (Fischer and Maurer 1978, Laing and Fischer 1977, Blum 1988, Ehdaie et al. 1988) have shown CIMMYT wheats to express a large "residual effect" of this high yield potential, when grown in dry conditions. In addition, traits representing specific adaptation to the stressed conditions are involved.

Identification of germplasm with mean superiority in dry environments is best carried out by also including in the final analysis its response in favorable environments (Ud-Din et al. 1993). Thus, its inherent yield potential can be "cleanly" evaluated. A very similar conclusion was reached by Zavala-Garcia et al. (1992) when working with sorghum, and Bramel-Cox et al. (1991). CIMMYT bread wheats owe a major part of their superior performance and acceptance in drought conditions to the high yield potential "engine" at their core.

Hamblin et al. (pers. comm.) argue that breeding under nonstressed conditions does effectively select for preserving leaf area and light-capturing ability, which serve well against, supposedly largely above-ground, biotic stresses encountered in relatively favorable, nonwater-limiting or only slightly stressed environments. However, since the major limitations in real stressed environments, according to their argument, are of a plant-internal and/or below-ground abiotic nature, such as water and cold stress, such an approach of protecting leaf area alone would be ineffective under those conditions. The authors conclude that specific adaptation breeding is needed for stressed environments. Above, however, we have emphasized that the efficient utilization of all (above- and below-ground) inputs is crucial to yield potential. We consider the presence of that foundation to be essential, after which necessary individual traits can be added. Hence, breeding germplasm for stressed environments is best done in a program that also develops germplasm for more favorable environments, since the latter contributes a crucial foundation for the for the first.

Therefore, while yield potential (best expressed and hence selected under optimum conditions) is a major component of yield under drought, various studies also show other traits to contribute, as would be expected.

In severe stress, below yield levels of 1-1.5 t/ha, tall wheats often do better than the very short semidwarfs (Laing and Fischer 1977, Richards 1992a,b). In late drought conditions, earlier maturity is a mechanism of escape. At the same time, the risk of late frost may require somewhat later flowering. In early drought conditions, the later varieties do better since they slow down their development sufficiently to benefit from the late rains. Waxiness may also be beneficial, but its contribution appears minimal (Johnson et al. 1983). Beyond these "common sense" traits, physiologists have not been able to add any traits of great significance (Marshall 1987).

Bread Wheat Program Methodology

Concepts

As discussed above, drought varies both between locations, that is to say "spatially", and across years or "temporally". In describing the response of lines to environmental variability, two expressions are commonly used: wide adaptation and stability. Wide adaptation is defined as the relative ability of a line to consistently yield in the upper percentile across different locations (spatially). Stability is defined as the relative ability of a line to consistently yield in the upper percentile over years (temporally).

From a breeding standpoint, what is the relation between those two modes of varietal behavior? Binswanger and Barah (1980) divide the relevant plant-independent variables into three types:

- Control variables: The experimenter decides on their presence or absence, and determines the degree. Examples are fertilizer, irrigation, and protective chemicals. These may vary across locations and years, depending on the experimenter's decision.
- Site variables: These are fixed givens, such as latitude, soil type, day length, or certain localized endemic pests (e.g., Hessian fly). They vary across sites, but not across years.
- Weather variables: These variables include such factors as total rainfall, its distribution, soil moisture, sunshine hours, cloudiness, temperature, etc. They vary across locations as well as over years, and do so in a similar manner.

In the case of drought, we are dealing with "weather variables", which vary similarly across locations as they do over years. This similarity allows us to use (spatial) adaptation as a measure of (temporal) stability in dry areas, while this would, for example, not be the case for response to soil acidity. Hence, multilocation testing, a procedure to gauge spatial adaptation, is used extensively by the Bread Wheat Program to identify temporally stable, drought tolerant germplasm.

Application

From the late 1960s until the early 1980s, several advanced lines were developed that found favor in dry areas, such as Kalyansona, Marcos Juarez INTA, Pavon, Nacozari, and Veery. These lines had not been bred/selected in drought conditions, but were shown to be well adapted as advanced lines. To a large extent, their response is considered due to the ever-increasing yield potential; the ability to be an optimum converter of inputs into outputs. Part of this ability is to respond with clear yield increases in those low frequency years when rainfall jumps significantly. However, in addition, the shuttle breeding program may well have contributed to selecting for certain traits that increase the plant's chances of expressing its potential, by protecting it against certain drought-related stresses.

By the mid-1980s, germplasm thus developed occupied 45% of the semi-arid wheat areas with rainfall between 300-500 mm, and 21% of the area with less than 300 mm (CIMMYT 1989). By 1990, 63% of the "dryland" area was planted to semidwarfs (Byerlee and Moya 1993), a major proportion of which is estimated to be CIMMYT-derived.

Since 1981, the selection process itself has been adapted to expose segregating material to alternate environments of drought stress and optimum conditions. Material grown in Toluca generally receives more than sufficient water. Alternate generations grown in Obregón are given only one (germination) irrigation. In combination with a generally low precipitation pattern in Obregón, plus a low amount of soil-stored moisture, this strategy generally results in a total water availability of 250-350 mm per crop cycle. Thus, the varying (both spatially and temporally) target environment is simulated by a varying range of available moisture during the selection process.

The traits used for selection of segregating generations are:

1) visual assessment of biomass (r_p may reach 0.55-0.94),
2) tiller survival,
3) green leaf duration (r_p may reach -0.31),
4) height (70-100 cm under drought)
5) grain plumpness,
6) hectoliter weight,
7) thousand kernel weight.

By the above described methodology of alternating environments for early generation selection, yield potential, which is best selected for under sufficient water (Toluca, high rainfall), is combined with any traits that are best selected for under drought (Obregón, one irrigation).

The final yield trials in Obregón of the advanced lines are carried out both in a one-irrigation environment (250-350 mm) and in a three-irrigation environment (400-550 mm), to simulate the range of water availability they will encounter in the target environment (250-600 mm).

By measuring yield itself, the highest level of integration of all contributions by the multitude of plant traits in the preceding periods of growth and development is gauged (Evans 1993).

Obviously, no trait can be selected for which the genes are not present in the parents. Initial parental choice is crucial. Therefore, many outstanding advanced lines, following international confirmation of their (spatial) adaptation and (temporal) stability are once again used as parents. Thus, the germplasm foundation is ever expanded and elevated.

The assumption in the above strategy is that yield potential traits and any specific drought-tolerance traits that may operate, are not incompatible. Major trade-offs between yield potential and drought resistance have rarely been shown to exist at the above 2 t/ha level.

It may be—and one should always be open to such a possibility—that there are real "drought tolerance" traits operating at the 1 t/ha and below level, that adversely affect high yield potential at the 4 t/ha and higher levels. In that case, however, respective NARSs should seriously consider if wheat should be the chosen crop. At such low yield levels, barley, sorghum, millets or a leguminous crop may be more agronomically realistic and economically profitable.

References

Allen, F.L., R.E. Comstock, and D.C. Rasmusson. 1978. Optimal environments for yield testing. Crop Sci. 18:747-751.

Arntzen, F. 1986. Plant Breeding Perspectives for Unfavorable Conditions; with emphasis on drought and low fertility in the tropics. Literature study, Wageningen Agricultural University, The Netherlands. 87 pp.

Binswanger, H.P., and B.C. Barah. 1980. Yield risk, risk aversion, and genotype selection: conceptual issues and approaches. Research Bulletin No. 3. ICRISAT, India.

Blum, A. 1988. Plant Breeding for Stress Environments. CRC Press.

Bolaños, J., and G.O. Edmeades. 1993. Eight cycles of selection for drought tolerance in lowland tropical maize. II. Responses in reproductive behavior. Field Crops Res. 31:253-268.

Bramel-Cox, P.J., T. Barker, F. Zaala-Garcia, and J.D. Eastin. 1991. In pages 29-56, Plant Breeding and Sustainable Agriculture: Considerations for Objectives and Methods. CSSA Special Publication No. 18.

Byerlee, D., and P. Moya. 1993. Impacts of International Wheat Breeding Research in the Developing World, 1966-1990. Mexico, D.F.: CIMMYT. 87 pp.

CIMMYT. 1989. 1987-1988 CIMMYT World Wheat Facts and Trends. The Wheat Revolution Revisited: Recent Trends and Future Challenges. Mexico, D.F.: CIMMYT. 57 pp.

Clarke, J.M., R.M. DePauw, and T.F. Townley-Smith. 1992. Evaluation of methods for quantification of drought tolerance in wheat. Crop Sci. 32:723-728.

Ehdaie, B., J.G. Waines, and A.E. Hall. 1988. Differential responses of landrace and improved spring wheat genotypes to stress environments. Crop Sci. 28:838-842.

Evans, L.T. 1993. Crop evolution, adaptation, and yield. University Press, UK. 500 pp.

Fischer, R.A. 1981. Optimizing the use of water and nitrogen through breeding of crops. Plant and Soil 58:249-278.

Fischer, R.A., and R. Maurer. 1978. Drought resistance in spring wheat cultivars. I. Grain yield responses. Aust. J. Agric. Res. 29:897-912.

Fischer, R.A., and J.T. Wood. 1979. Drought resistance in spring wheat cultivars. III. Yield associations with morpho-physical traits. Aust. J. Agric. Res. 30:1001-1020.

Johnson, D.A., R.A. Richards, and N.C. Turner. 1983. Yield, water relations, gas exchange, and surface reflectances of near-isogenic wheat lines differing in glaucousness. Crop Sci. 23:318-325.

Laing, D.R., and R.A. Fischer. 1977. Adaptation of semi-dwarf wheat cultivars to rainfed conditions. Euphytica 26:129-139.

Marshall, D.R. 1987. Australian plant breeding strategies for rainfed areas. In pages 89-100, J.P. Srivastava, E. Porceddu, E. Acevedo, and S. Varma, eds., Drought Tolerance in Winter Cereals. John Wiley & Sons, UK.

Ud-Din, N., B.F. Carvar, and A.C. Clutter. 1993. Genetic analysis and selection for wheat yield in drought-stressed and irrigated environments. Euphytica 62:89-96.

Parlevliet, J.E., A.A. de Haane, and J.J.A.M. Schellekens. 1991. Drought Tolerance Research: Possibilities and Constraints. Wageningen Agricultural University. 44 pp.

Rajaram, S. 1991. Mejoramiento de trigo para obtener tolerancia a la sequia: Perspectivas y opiniones. In pages 149-163, M.M. Kohli, ed., Mejoramiento de la resistencia al sequia en trigo. Mexico, D.F.: CIMMYT.

Richards, R.A. 1992a. The effect of dwarfing genes in spring wheat in dry environments. I. Agronomic characteristics. Aust. J. Agric. Res. 43:517-527.

Richards, R.A. 1992b. The effect of dwarfing genes in spring wheat in dry environments. II. Growth, water use and water-use efficiency. Aust. J. Agric. Res. 43:529-539.

Zavala-Garcia. F., P.J. Bramel-Cox, J.D. Easin, M.D. Witt, and D.J. Andrews. 1992. Increasing the efficiency of crop selection for unpredictable environments. Crop Sci. 32:51-57.

Chapter 5.

Bread Wheat Breeding for Heat Tolerance

Alexei Morgunov

Introduction

Modern varieties of wheat are well adapted to controlled cultural practices, but they are generally not highly tolerant to extreme environmental stresses, such as high temperature. Heat stress reduces wheat production in many areas of the world. In the rice-wheat cropping system, crop damage due to high temperatures under late planting conditions has become an important yield-limiting factor, especially in the Indian Subcontinent, Yangtze River Basin of China, and in tropical regions. The varieties of one region are generally not suitable for the others, and separate breeding objectives will be needed for each situation (Rajaram 1988).

Fischer and Maurer (1976) demonstrated that a 1°C rise in temperature above ambient during the period between the end of tillering and the beginning of grain-filling reduced grain yield by 4%. Since plant tolerance to temperature stress is heritable, selection and breeding can be used to improve this trait. Breeding cultivars with improved tolerance to temperature, however, is a difficult task because of the following reasons:

- Limited understanding of the genetic and physiological bases of heat tolerance in plants;
- Confounding effects of heat and drought stress;
- Limited understanding of what stages of plant growth can be used as selection criteria;
- Lack of efficient and accurate tests to select for the component physiological mechanisms that give heat tolerance.

Physiologists have demonstrated that tolerance to temperature stress is correlated with many component traits, but none of the physiological or morphological characters have exhibited consistent response correlated with heat tolerance. The physiological relationships involved are complex, as are the combination of genes for heat tolerance that must be added to the genes necessary for superior performance. Breeders must evaluate an enormous number of genotypes because the discovery of a plant with all the required genes is highly improbable. In fact, wheat varieties have been developed with tolerance to abiotic stresses, including heat, for many decades, without a full awareness of the selective effects of the environments where the selections took place.

Genetic Variability for Heat Tolerance

Genetic variability exists in regards to tolerance to high temperature. Kanani and Jadon (1985) assessed 110 genotypes of bread wheat in India and found 18 genotypes (including HINDI62, C306, K65, and NP876) to be suitable for growing under high temperatures.

Shpiler and Blum (1986) reported a study of 20 spring wheats of Israeli origin in three normal winter and two spring cycles. They concluded that selection for good tillering and long spikes with a large number of spikelets will improve wheat productivity and stability in hot environments.

Bruckner and Frohberg (1987) evaluated 20 genetically diverse spring wheat genotypes in North Dakota. They found variation for both rate and duration of grain-filling, but increasing temperatures during grain-filling halted grain growth prematurely and hastened physiologic maturity. Rate, but not duration, of grain-filling correlated with kernel weight. They suggested that selection for increases in both grain-filling rate and kernel weight is possible. Thus, high grain-filling rates with short-to-medium grain-filling duration are desirable.

Dieseth (1990), who conducted a detailed experiment on 25 genotypes planted on five dates from 6 November to 28 February in Ciudad Obregón, reported that tiller survival was the most affected character in heat stress. The spike number was reduced by 26% when planting was delayed from 1 December to 28 February. Also, the number of grains/spike decreased, mainly a result of fewer grains/spikelets. Kernel weight was reduced moderately, as most of the genotypes produced plump grains with high test weight under high temperature conditions, indicating that yield was mainly sink-limited. He suggested that spike fertility and capacity to compensate for decreased spike number might be easier to improve than tiller survival.

From the results of the First International Heat Stress Genotype Experiment conducted at 13 locations, Reynolds et al. (1992) concluded that the total biomass and spikes/m^2, are well correlated with yield. Late-maturing genotypes had disadvantage under heat stress.

Damania and Tahir (1993) studied 46 wheat and wild progenitors for heat tolerance. They found that cultivated wheat with a genomic composition of AABB and its wild progenitors are tolerant to heat, and this seems to be associated with ecological distribution and origin. For centuries after domestication, *T. durum* was grown mainly in the Mediterranean and West Asia, where terminal heat is one of the major stresses.

Hu and Rajaram (1994) studied 16 bread wheat genotypes for two years in late plantings and one year under normal plantings at Ciudad Obregón, Sonora. They concluded that grains/spike, biomass, harvest index, and test weight could be considered potential selection criteria for grain yield under high temperature.

Germplasm Improvement

Historical background

The international nursery network during the 1960s and 1970s allowed the identification of superior varieties adapted to some of the warmer regions. Early maturing germplasm such as Sonora 64, Inia 66, and Sonalika found immediate acceptance in the warmer areas. Wider testing has demonstrated some advantage in favor of germplasm of intermediate maturity such as Siete Cerros, Anza, Jupateco 73, and Anahuac 75 in parts of Africa and South America.

UNDP/CIMMYT Program

Support of the United Nations Development Programme (UNDP), which was started in 1982 and extended in 1987 and 1990, has enabled CIMMYT to expand research on the development of high yielding, disease resistant, semidwarf wheats adapted to warmer areas of the world. With the aid of UNDP, CIMMYT's wheat program has been able to target heat tolerance as a breeding objective and to

systematically mobilize the independent activities of national programs more effectively. Beginning with its own germplasm collection and that gathered over the years from national programs, CIMMYT selected known heat-tolerant varieties, placed these into a specialized nursery, called Heat Tolerance Screening Nursery (HTSN) and sent them to "hot spots" around the globe for evaluation in 1982.

Locations in Mexico

Two locations are used for heat tolerance evaluation: 1) Ciudad Obregón, Sonora (27°N, 39 masl) and 2) Poza Rica (21°N, 60 masl). Selection for heat-tolerant genotypes is done by screening advanced lines under late planting conditions with full irrigation in Cd. Obregón. The late planting after 20 January results in flowering during late March when temperatures are hot. The timely planted (November) wheats mature in mid-April, while the January-planted crops reach physiological maturity in mid-May. In general, late-planted wheats in the Yaqui Valley have continuous exposure to high temperatures, especially at the critical stages of flowering and grain-filling like that on the Subcontinent. At Poza Rica, temperature stress occurs from the early growth stage through maturity like in the tropical regions.

Breeding strategy

Since genetic variability exists in regard to tolerance to high temperatures, there have been recent attempts at CIMMYT to identify the best genotypes. An Indian variety, Sonalika (originally bred in Mexico by CIMMYT), is an example of a variety suitable for late planting on the Subcontinent. This variety escapes heat exposure because it matures very early. However, because of its earliness, it has less biomass production and less yield potential. Medium maturity would permit manipulation of higher biomass and yield potential, while heat tolerance would protect that yield from being eroded.

Selection methodology and criteria should ensure development of varieties of wide adaptation and acceptance. CIMMYT's empirical methodology is to combine high yield potential under favorable conditions with a certain degree of tolerance to heat. These two characteristics can be combined in a single breeding program. This breeding methodology is based on the fact that selection for heat tolerance started from early generations can lead to specifically adapted germplasm with a possible loss in yield potential. On the other hand, breeding for vigorous genotypes well suited for optimal nonstress conditions will maintain a certain level of heat tolerance.

The crossing blocks for favorable environments (ME1) and tropical environments (ME5) have sections of heat-tolerant lines. They represent either genotypes cultivated in areas where heat stress is common or superior lines identified under late planting in CIMMYT. High yielding lines are crossed to the known heat tolerant stocks and the material is advanced until F6-F7 under nonstress environment in Cd. Obregón and Toluca. Effective selection based on individual plant responses for heat tolerance may not be feasible, but some improvement in replicated progeny testing should be possible. When the lines reach preliminary yield test, they are planted simultaneously at optimum and late planting in Cd. Obregón, where 30°C occurs very frequently during the grain-filling stage in late April and May. The best lines from the PYT are promoted to the replicated yield trials. Those genotypes that demonstrate yield advantage compared to checks are considered as candidates for the International High Temperature Wheat Yield Trial. Tables 5.1 and 5.2 present some bread wheat lines with good performance under high temperature, late planting conditions during the Yaqui 1991-92 and 1992-93 seasons. The characters that CIMMYT applies as selection criteria for tolerance to high temperature are in Table 5.3.

Table 5.1. Top yielding bread wheat lines under high temperature. Late planting (March), Yaqui, 1991-92.

Cross and selection	Yield (t/ha)	% of BCN	Test weight (g)
TURACO CM90312-C-8B-8Y-1B-0Y	1.89	116	75.8
MYNA/VUL//PRL CM97958-0M-7Y-030M-030M-3Y-0Y	1.77	112	74.2
BOW/PRL CM83274-9B-07Y-01M-1Y-6B-0Y	1.76	147	77.0
KAUZ CM67458-4Y-1M-3Y-1M-3Y-0B	1.75	116	76.2
VEE#5//PF70354/MUS CM79929-11Y-025H-0Y-1M-2Y-0M	1.71	143	74.0
SARA/THB//VEE CM87582-013TOPM-2Y-0H-0SY-1M-0Y	1.68	119	75.0
CNO79/PRL CM83271-26Y-4B-1Y-1B-0Y	1.67	139	75.6
KAUZ/GEN CRG78.2-56B-0Y-O30M-7Y-2Y-0M	1.54	115	74.2
KAUZ*2/TRAP//KAUZ CRG744-9Y-010M-0Y	1.49	128	76.4
FASAN CM66246-C-1M-1Y-1M-2Y-0M-19M-0Y	1.48	122	78.8
BUC/PRL VAN854-36U-36C-6Y-0B	1.44	128	74.6

Table 5.2. Top yielding lines with high yield performance in late planting (March), Yaqui, 1992-93.

Cross and selection	Yield (t/ha)	% of BCN	% of OPATA	Test weight
TURACO CM90312-D-2B-15Y-2B-OY	3.37	131[a]	160	78.7
PGO/SERI//BAU CM91927-O-0Y-0M-0Y-3M-0Y	3.36	130[a]	160	75.8
TRAP#1/BOW CM84548-34Y-0M-0Y-8M-0Y	3.32	129[a]	158	78.6
RHEA TE82.0009-5Y-025H-0Y-10M-0Y	3.25	126[a]	155	76.8
JUP/ZP//COC/3/PVN/4/GEN CM93697-11M-0Y-0M-5Y-0B	3.11	120[a]	148	75.6
PFAU/VEE#9//URES CM94295-F-0M-0Y-0M-3Y-0B	3.10	120[a]	148	77.6
ANGRA CM59123-3M-1Y-2M-1Y-2M-2Y-0M	3.03	122	-	-
PAT10/ALD//PAT72300/3/PVN/4/BOW CM84490-6M-0SY-0H-9Y-0M-7M-0HER	2.92	129	142	77.2
ND/VG9144//KAL/BB/3/YACO/4/CHIL CM90461-6Y-0M-0Y-2M-0Y	2.74	118	165	77.7
TURACO/CHIL CM92354-33M-0Y-0M-3Y-0B	2.68	115	177	78.2
CHIL/BUC CM93687-55M-0Y-0M-3Y-0B	2.59	119	143	77.4
TOW/SARA//BAU CM91661-M-0Y-OM-0Y-2M-0Y-3M-0HER	2.57	117	146	76.7
CETTIA CM92313-24M-0Y-0M-3Y-0B-0SY	2.55	116	145	79.9

[a] % of ARIVECHI used as local check.

It is absolutely clear that high temperature stress indirectly reduces yield by directly affecting various yield components. Hence, yield as a criterion to select against heat stress, especially in yield trials, remains the most reliable yardstick. However, at the segregating population level, yield cannot be deployed as a salient criterion because it would involve harvesting, threshing, and weighing a large, unmanageable number of lines—especially under the circumstances of the CIMMYT program. Based on the experience of the CIMMYT Wheat Program and others, it is suggested that a combination of empirical observations and quantitative measurements might be the best route for selecting bread wheats that are tolerant to heat stress. When thousands of lines are deployed in segregating populations, an experienced plant breeder can make relatively subjective judgements on biomass, number of spikes, tillering capacity, stand establishment, leaf senescence, and grain-filling period. This empirical judgement should be supported by properly analyzed yield trials and quantitative measurements to support the associations of characters involved in heat stress tolerance.

Table 5.3. Characters possibly involved in tolerance to high temperatures.

Characters	Genetic variability available	Empirical selection possible
High stand establishment	+	+
Good tillering	+	+
Delayed leaf senescence	+	+
Grain plumpness/High test weight	+	+
Good spike fertility	+	+
Medium maturity	+	+
High biomass	+	+
Accelerated grain-filling period	+	+

International testing is useful to identify potentially useful germplasm for cultivar use. Stability of performance under different high temperature environments is one of CIMMYT's most important breeding criteria. Results of the International Heat Stress Genotype Trial conducted by CIMMYT physiology group during 1990-91 at 10 locations are presented in Table 5.4. SERI M 82 gave the highest yield followed by NESSER, GLENNSON M 81, FANG 60, GENARO T 81, and PAVON F 76. The high yielding lines SERI M 82, GLENNSON M 81, and GENARO T 81 are sister lines of the VEERY cross. The VEERY class of varieties (HUW206, GENARO T 81, URES 81, SERI M 82) have been recommended in tropical areas of the world including Myanmar, Bangladesh, Paraguay, eastern India, southern Pakistan, and Guatemala. Better material

Table 5.4. Mean yield performance of genotypes in the First Inter-national Heat Stress Genotype Trial, 1990-91.

Genotypes	Yield (t/ha)
SERI M 82	3.54
NESSER	3.20
GLENNSON M 81	3.18
FANG 60	3.15
GENARO T 81	3.08
PAVON F 76	3.07
NACOZARI 76	3.02
CNO 79	2.97
BACANORA T 88	2.97
ANZA	2.92
KANCHAN	2.91
DEBEIRA	2.87
7 CERROS	2.60
IP 4	2.42
SONORA 64	2.26
TRIGO 3	2.15

Locations: Bangladesh, Brazil, India, Sudan, Syria, Thailand, Mexico (Tlaltizapan—two trials, Obregón—two trials).

than VEERY is coming up as is clear from the yield data of First International Heat Tolerance Wheat Yield Trial conducted during 1992-93 (Table 5.5). The line PFAU/VEE#9//URES gave the highest yield (Figure 5.1) followed by TURACO, a sister line of PFAU/VEE#9//URES, TIA 1, and JUP/ZP//COC/3/PVN/4/GEN. The yield ranged from 3.83 for PFAU/VEE#9//URES to 3.19 t/ha for KANCHAN.

Table 5.5. Average yield performance (t/ha) of lines tested in the First International Heat Tolerance Yield Trial, 1992-93.

Line/variety	Average yield (t/ha)
1. PFAU/VEE#9//URES	3.83
2. TURACO	3.77
3. PFAU/VEE#9//URES	3.72
4. TIA 1	3.71
5. JUP/ZP//COC/3/PVN/4/GEN	3.71
6. INIA66/AGD1//INIA66/3/2*CNO79	3.67
7. TIA 3	3.65
8. LOCAL CHECK	3.65
9. BOW//BUC/BUL	3.59
10. RHEA	3.59
11. PFAU/VEE#9	3.59
12. PFAU/VEE#5	3.54
13. SERI M 82	3.54
14. TRAP#1/BOW	3.53
15. PVN//YD/SLM/3/CHAT	3.51
16. RHEA	3.49
17. PGO/SERI//BAU	3.48
18. F12.71/COC//GEN	3.48
19. JUP/ZP//COC/3/PVN/4/GEN	3.45
20. RHEA	3.44
21. TOW/SARA//BAU	3.43
22. RHEA	3.41
23. STAR	3.38
24. FANG 60	3.36
25. COOK/VEE//DOVE/SERI/3/BJY/COC	3.34
26. F60314.76/MRL//CNO79	3.33
27. BNQ/PVN//PVN	3.28
28. OPATA M 85	3.25
29. SKA	3.22
30. KANCHAN	3.19

Locations: Mexico (CIANO), Sudan (Gezira), Syria (Tel-Hadya), Egypt (Shandaweel), Yemen (Seiyun), Cyprus (Athalassa), Qatar (Rawdat Harma), Tunisia (Kef), S. Africa (Bethlehem), Thailand (Lampang & Chumphae), Nepal (Bhairahawa), and Pakistan (Islamabad and Sindh).

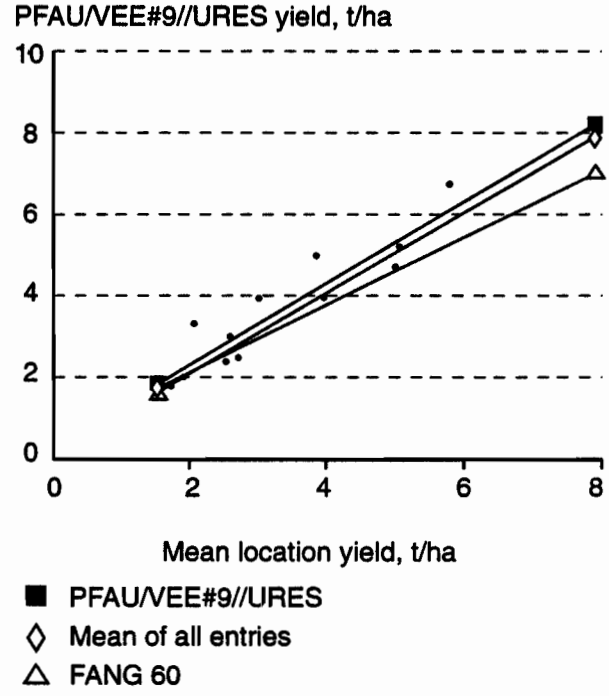


Figure 5.1. Performance of PFAU/VEE#9// URES and the mean of all entries in the 1st HTWYT.

References

Bruckner, P.L., and R.C. Frohberg. 1987. Stress tolerance and adaptation in spring wheat. Crop Sci. 27:31-36.

Damania, A.B., and M. Tahir. 1993. Heat and cold tolerance in wild relatives and primitive forms of wheat. In pages 217-224, A.B. Damania, ed. Biodiversity and Wheat Improvement. ICARDA.

Dieseth, J.A. 1990. Growth and development of bread wheat under high temperature. PhD Thesis, Agric. Univ. of Norway.

Fischer, R.A., and R.O. Maurer. 1976. Crop temperature modification and yield potential in a dwarf spring wheat. Crop Sci. 16:855-859.

Hu, H.Z., and S. Rajaram. 1994. Differential responses of bread characters to high temperature. Euphytica (in press).

Kanani, P.K., and B.S. Jadon. 1985. Variability for high temperature tolerance in bread wheats. Indian J. Agri. Sci. 55:63-66.

Rajaram, S. 1988. Breeding and testing strategies to develop wheats for rice-wheat rotation areas. In pages 187-196, A.R. Klatt, ed., Wheat Production Constraints in Tropical Environments. Mexico, D.F.: CIMMYT.

Reynolds, M.P., E. Acevedo, O.A.A. Ageeb, S. Ahmed, M. Balota, L.J.B. Carvalho, R.A. Fischer, E. Ghanem, R.R. Hanchinal, C.E. Mann, L. Okuyama, L.B. Olugbemi, G. Ortiz Ferrara, M.A. Razzaque, and J.P. Tandon. 1992. Results of the 1st international heat stress genotype experiment. Wheat Special Report No. 14. Mexico, D.F.: CIMMYT.

Shpiler, L., and A. Blum. 1986. Differential reaction of wheat cultivars to hot environments. Euphytica 35:483-492.

Chapter 6.

Bread Wheat Breeding for Karnal Bunt Resistance

Gurdev Singh

Introduction

Karnal bunt (KB) or partial bunt of wheat caused by *Tilletia indica* (Mitra) [Syn. *Nevossia indica* (Mitra) Mundkar] is a floral-infecting disease that partially infects seed of bread wheat, durum wheat, and triticale. The fungus infects the plant at the boot stage, but the disease becomes evident only when the grains are formed and become mature. In the case of an infected plant, not all the ears show infection and all the grains in an ear are not infected. Some individual grains in a diseased head are completely infected, whereas most of the affected grains are partly infected.

KB is seedborne and, once introduced into an area, the teliospores of the fungus can survive in the soil for several years. The seed and soilborne teliospores of the fungus represent the source of infection by germinating in the soil, producing filiform and allantoid sporidia, which presumably multiply to large numbers under favorable weather conditions. These are believed to be the propagules that are responsible for infection at the flowering time of wheat.

KB is prevalent in some important wheat growing areas of India, Pakistan, and Mexico. It is estimated that about 10 million hectares are affected by KB. Several countries have adopted stringent quarantine measures, which have worldwide implications, not only on wheat trade, but on wheat research as well.

History and Distribution

KB was first reported by Mitra in 1931 near the northern Indian city of Karnal in Haryana State. He suspected that it might have been described earlier by Howard and Howard from Lyallpur (now Faislabad in Pakistan) in 1908. This disease, in all likelihood, originated on the Subcontinent of India.

In 1934, KB was reported in an epidemic at Karnal and in 1941, the disease was found on wheat in Sind Province (Pakistan) and in Uttar Pradesh and Delhi, India (Mundkur 1944). By 1943, it was prevalent in the Punjab State of India and Punjab and North-West Frontier Provinces of Pakistan. In 1948, serious damage was reported in the Punjab and North-West Frontier Provinces of Pakistan. KB was considered a minor disease of wheat and more of curiosity than an economic problem in India until the late 1960s. In 1970, the disease appeared in a severe form in the Indian states of Jammu and Kashmir, Punjab, Haryana, Himachal Pradesh, Uttar Pradesh, Delhi, and Rajasthan and Punjab of Pakistan. A significant increase in the incidence level was experienced in the 1970s due to factors involving favorable weather, increased inputs, changes in the cropping pattern, and the release of susceptible cultivars (Singh et al. 1977). In India, KB epidemics were recorded in 1930, 1931, 1933, 1942, 1948, 1954, 1956, 1968, 1973, 1975, 1976, 1978, 1979, 1980, 1981, 1982, 1983, and 1986.

The first report of KB in Mexico came from the Yaqui Valley, Sonora, in the late 1960s (Duran 1972). However, the first significant outbreak to receive attention occurred in 1983. The infected area in three

states (Sonora, Sinaloa, and Baja California Sur) was estimated to be 38,000 ha. Surveys conducted in the Yaqui Valley, Sonora, Mexico, showed that 8, 68, 1, and 72% of the collected samples were infected during 1982, 1983, 1984, and 1985, respectively. In this valley, only 10% of the farmers have had more than 1% of their grain infected by the disease in a year with severe infection. In the Yaqui Valley, the highest incidence recorded has been 20%, but this is very rare.

In northern India, Munjal (1975) estimated the loss in grain yield of 0.2%, equivalent to 40,000 t/grain/year. The study conducted in northwestern Mexico reported that yield losses due to KB amount to 0.12%/year (Brennan et al. 1990). The study also listed the major components of total costs, such as quality of the infected crop (37%), losses from restrictions on planting (29%), and an estimated loss of wheat seed export (16%).

Epidemiology

Weather at the time of flowering strongly influences the amount of infection of the disease. Nagarajan and Saari (1992) statistically analyzed the weather and incidence data from India and Mexico using simple and multiple regression. Intermittent rain and sunshine appear to favor allantoid sporidia multiplication and infection. The analysis suggested that the number of rainy days at the flag leaf stage of the wheat plant's growth was the single most important factor in the occurrence and severity level of the disease.

The analysis suggests that, in northwestern India, the number of rainy days and the amount of rain in February were the dominant factors in KB infection and development. An R^2 value of 0.85 was derived, using three parameters, rainy days between 15-21 Feb., rainy days between 22-28 Feb., and mean maximum temperature in °C. Rain during the week of 15-21 Feb. was the single most important variable with an R^2 value of 0.75.

Rainfall also influences temperature and has a tendency to reduce maximum temperatures. Maximum high temperatures in March are negatively correlated with KB incidence. Weather conditions in late March and conditions prior to February appear to have little influence on KB.

In Mexico, the analysis showed that the number of rainy days in February appears to be the dominant factor influencing the KB incidence. In Mexico, the rainy days during 1-7 Feb. coincides with the heading period for wheat. In northwestern India, the rainy days during the week of 15-21 Feb. also coincide with the heading period. The amount of rainfall is not as important as its frequency.

Resistance Sources

For the identification of resistant sources, the reliable screening technique is the first prerequisite. Since the natural occurrence of the disease in the Yaqui Valley, Sonora, Mexico, varies from one year to another, artificial inoculation of the experimental germplasm is necessary. Inoculum, which is provided by the CP Subprogram, is prepared using cultures derived from teliospores collected at various locations in the Yaqui Valley. About 2 ml of inoculum with a concentration of 10,000 sporidia/ml are injected into the boot of 10 spikes from each line. The lines are planted on two or three dates to avoid any possible escapes. Inoculations are done in the afternoon and an overhead

irrigation system is used to create the high relative humidity for successful infection. Lines with less than 5% infection are selected and subsequently tested continuously each year to evaluate stability for resistance (Fuentes-Davila 1992).

Resistance was observed in the following types of germplasm:

- Chinese lines from Yangtze region, such as Shanghai#8.
- Brazilian lines, such as IAS 20.
- Indian lines, such as HD 29.
- Durum wheats, such as Altar 84.
- Synthetics, such as Chen/*Triticum tauschii*.

Specific lines with confirmed resistance to KB are listed in Table 6.1.

Breeding for Karnal Bunt Resistance

The yield potential of CIMMYT's bread wheat germplasm has continually increased at the rate of 1%/year since 1950. Despite this spectacular increase, most of the germplasm was inherently susceptible to KB. The KB teliospores are resistant to extreme cold, heat, and chemical treatment and they can survive for more than 5 years in the soil, which makes control difficult. Fungicide application during flowering can reduce the infection in the field, however, this is an expensive practice for farmers. CIMMYT is looking for a more practical solution for the farmers in countries where the disease is present. Breeding for resistance to KB is the most effective and feasible means of disease control. The systematic breeding program to develop resistant varieties was started with the identification of resistant sources.

Table 6.1. Karnal bunt-resistant stocks.

Stocks	Origin
Sha#7	China
Sha#8	China
Suz#1	China
Suz#6	China
YMI#6	China
HD 29	India
HD 30	India
WL6975	India
W499	India
RC7201/2*BR	Brazil
Aldan/IAS58	Brazil
PF71131	Brazil
Cruz Alta	Brazil
Jacana	Mexico
Amsel	Mexico
Para2//Jup/BJY/3/Vee#5/4/Jun	Mexico
Nanjing 8343/KAUZ	Mexico
Nanjing 82149/KAUZ	Mexico
Luan	Mexico
YMI #6/GEN//TIA.1	Mexico
CMH77.308	Mexico
CMH83.3252	Mexico
Chen/*Ae. squarrosa*	Mexico
Roek//Maya/Nac	Mexico
Weaver	Mexico
Star	Mexico
Chris	USA
K342	Pakistan

In 1984, CIMMYT introduced a set of Chinese advanced lines (Wuhan, Shanghai, and Suzhoe) from the Yangtze region of China (Rajaram et al. 1992). These lines were resistant to head scab (*Fusarium graminearum*), but were also found to be resistant to KB after tests in the Yaqui Valley. To transfer the head scab resistance from Chinese germplasm, a large-scale crossing program with CIMMYT lines produced 266 advanced lines presumably tolerant to *Fusarium* and supposedly resistant to KB. These advanced lines were subjected to intensive artificial inoculation in 1991 in the Yaqui Valley. Two KB-resistant varieties have been released by the Mexican national program (INIFAP):

- For northern Sinaloa [Guamuchil 92 (= Catbird) = Chuan Mai #18/Bau; CM91045-6Y-0M-1M-9Y-0B].
- For southern Sonora [Arivechi 92 (=Luan) = Wuh/Glen/4/Inia/*A.dist*//Inia/3/Gen; CM100587-E-0M-0Y-030M-8Y-1Y-0M].

Weaver, another pre-release line, is high yielding and resistant to KB.

Breeding methodology

The following methodology was used to produce the above germplasm:

- High yielding germplasm is crossed with KB-resistant lines and top crossed to better quality parents.
- Shuttling of segregating populations between Cd. Obregón and Toluca and selection for good agronomic types and disease resistance.
- Screening for resistance in segregating populations is done under artificial inoculation in Cd. Obregón.
- Preliminary yield trials (PYT) and yield trials (YT) are conducted in Cd. Obregón.
- Advanced lines in the PYT and YT are screened for their resistance under artificial inoculations.

During Yaqui 1992-93, advanced lines were yield-tested in the PYT and YT. Lines, which out-yielded Bacanora T 88 by a margin of 10% in the PYT, are listed in Table 6.2. These high yielding lines are

Table 6.2. Top yielding lines from PYTME1KB (Yaqui 1992-93).

Cross and selection	Yield (t/ha)	% of BCN	Suspected Source
CHEN/*T.tauschii*/BCN CMBW89Y3528-5Y-010M-010Y-18M -5Y 0M	7.74	121	Alien+Durum
VEE/PJN//KAUZ CM107561-5Y-020Y-010M-4Y-010M-7Y-0M	7.18	119	Brazil
PJN/BOW//OPATA CM107553-18Y-020Y-010M-8Y-010M-8Y-0M	7.06	114	Argentina
CNDO/R143//ENTE/MEXI/3/*AE.SQUAR./4/* WEAVER CMBW89Y3496-4Y-010M-010Y- 50M-2Y-0M	6.83	134	Alien+Durum
KAUZ*3/4/FG/ATO//HUI/ROK CM109300-OTOPM-030Y-020Y-010M-010Y-010M-3Y-0M	6.78	111	Durum
ALTAR84/*T.tauschii*//OCI CMBW89Y3516-1Y-010M-010Y-3M-2Y-0M	6.77	122	Alien+Durum
MUNIA//CHEN/ALTAR84 CM111594-15M-020Y-010M-010Y-010M-4Y-0M	6.73	110	Durum
CHEN/*T.tauschii*/BCN CMBW89Y3554-2Y-020Y-010Y-2Y-010M -1Y-0M	6.73	114	Alien+Durum
PJN/BOW//OPATA CM107553-18Y-020Y-010M-2Y-010M-1Y-0M	6.73	123	Argentina
PEL72380/ATR71//H567.71/3/TUI CM107486-3Y-020Y-010M-1Y-010M-1Y-0M	6.69	113	Brazil
HPO/TAN//VEE/3/2*PGO CM112754-OTOPY-22M-020Y-010M-4Y- 010M-1Y-OM	6.66	117	Mexico
PARANA#2//JUP/BJY/3/VEE/JUN/4/2*KAUZ CMBW89M7300-OTOPY-030M-8Y-010M-1Y-0M	6.63	111	Argentina
MYNA/VULTURE//TURACO/3/TURACO CMBW89Y01234OTOPM-18Y-010M-2Y-010M-5Y-OM	6.54	110	Mexico
CHEN/*T.tauschii*//TURACO CMBW89Y3552-1Y-010M-010Y-16M-1Y-0M	6.37	112	Alien+Durum
VEE/MJI//TUI CM107511-1Y-020Y-010M-1Y-010M-5Y-0M	6.30	118	Argentina

resistant to KB and leaf rust. Most of these lines are a product of crosses between synthetic bread wheats (durum wheat x *T. tauschii*) and bread wheat and represent new variability in CIMMYT germplasm. One such line Chen/*T. tauschii*)//Bcn yielded 21 and 34% higher than Bacanora T 88 and Weaver, respectively.

During the Toluca 93 and Cd. Obregón 93-94 cycles, 22,480 KB segregating/advance lines have been and are being tested and evaluated for agronomic types and other disease resistance (Table 6.3). In replicated yield trials, 848 lines and 1758 advanced lines in unreplicated yield trials are being tested in Cd. Obregón 1993-94 cycle.

Genetics of Karnal Bunt Resistance

Attempts to study the genetics of KB resistance were made only recently at CIMMYT and Punjab Agricultural University, Ludhiana, India. Chand et al.(1989) and Gill et al.(1990) reported partial dominance of resistance to KB. These studies reported that additive and additive x additive type of gene actions were more important in the inheritance of KB resistance. At CIMMYT, three genetic studies were concluded during the Cd. Obregón 1992-93 cycle. The diallel crosses were attempted in all three studies and the parents, F1s, and F3s were subjected to artificial inoculation for KB fungus. The F1 data in these studies showed that resistance is partially dominant over susceptibility.

The first study involved six resistant (Chris, CMH 77.308, Amsel, PF 71131, Shanghai #8, Para2//Jup/Bjy/3/Vee #5/Jun) and one susceptible (WL 711) parents. Chris, Amsel, and PF 71131 have one dominant gene each, CMH 77.308 and Shanghai #8 carried two dominant genes while Para2//Jup/Bjy/3/Vee#5/Jun have two recessive genes for resistance (Table 6.4). The crosses among resistant parents indicated that Chris, Amsel and PF 71131 have different genes for resistance while Chris and CMH77.308 have one common gene and CMH77.308, PF 71131 and Shanghai #8 have another different common gene. In this population, six different genes control the resistance.

Table 6.3. Karnal bunt segregating/advanced lines during MV-93 and Y93-94 cycles.

Generations/trials	Toluca 93	Cd. Obregón 93-94
F1 (Simple)	126	55
F1 (Top)	90	75
F2	124	67
F3	456	108
F4	2,451	103
F5	593	844
F6	1,212	236
F7	-	7,827
PC	2,652	1,480
EPC	667	709
PYT	-	1,758
YT	-	848
Total	8,370	14,010
Grand total		22,480

Table 6.4. Number of genes controlling Karnal bunt resistance in different resistant stocks.

Country of origin	Resistant lines	Number of genes
Brazil	RC7201/2*BR	1 Dominant
	ALDAN/IAS58	3 Dominant
	PF71131	1 Dominant
	CRUZ ALTA	1 Dominant
China	SHANGHAI #7	2 Dominant
	SHANGHAI #8	2 Dominant
India	W 499	1 Dominant
Pakistan	K 342	1 Dominant
USA	CHRIS	1 Dominant
Mexico (CIMMYT)	WEAVER	1 Dominant
	AMSEL	1 Dominant
	CMH 77.308	2 Dominant
	ROEK//MAYA/NAC	1 Dominant
	PARA2//JUP/BJY/3/VEE#5/JUN	2 Recessive

In the second study, four resistant (Roek//Maya/Nac, RC7201/2*BR2, Aldan/IAS58 and Shanghai #7) and one susceptible (WL 711) parents were involved. Roek//Maya/Nac and RC7201/2*BR2 carried one dominant gene for resistance while Shanghai #7 and Aldan/IAS58 have two and three genes, respectively (Table 6.4). In the F3 progenies, no segregation was observed in resistant x resistant crosses, indicating that one common gene was present in all four resistant parents, which imparted a high level resistance.

In the third study, four resistant (Weaver, W499, Cruz Alta, and K342) and two susceptible (LAJ 3302 and WL3399) parents were crossed in all possible combinations. Monogenic control of resistance was observed in all the resistant parents. Weaver, W499 and Cruz Alta have different genes while Cruz Alta and K342 have same gene for resistance.

Diallel crosses were attempted for 14 resistant parents used in these studies to further determine the allelic relationship among all the resistant lines.

Since only one or a few genes need to be combined to achieve low level of infection, breeding for KB resistance in combination with high yield potential may not be difficult. As is evident from the yield trial data of Y92-93 (Table 6.2), we believe this could be a genetic breakthrough in reducing the epidemic.

References

Brennan, J.P., E.J. Warham, J. Hernandez, D. Byerlee, and F. Coronel. 1990. Economic losses from Karnal bunt of wheat in Mexico. CIMMYT Economics Work Paper 90/02.

Chand, K., K.S. Gill, G.S. Nanda, and G. Singh. 1989. Genetic analysis of Karnal bunt resistance in bread wheat. Crop Improv. 16:178-179.

Fuentes-Davila, G. 1992. Identification of sources of resistance in *Tilletia indica*. In pages 12-13, G. Fuentes-Davila and G.P. Hettel, eds., Update on Karnal Bunt Research in Mexico. CIMMYT Wheat Special Report No. 7a.

Gill, K. S., G.S. Nanda, G. Singh, K. Chand, S.S. Aujla, and I. Sharma. 1990. Study of gene effects for Karnal bunt resistance in bread wheat. Indian J. Genet. 50:205-209.

Lira, M. 1984. The Karnal bunt situation in northwest Mexico. In page 24, Karnal Bunt Disease of Wheat, Proceedings of the Conference. CIMMYT.

Mundkur, B.B. 1944. Some rare and new smuts from India. Indian J. Agril. Sci. 14:49-52.

Nagarajan, S., and E.E. Saari. 1992. Epidemiology of Karnal bunt. In pages 19-20, G. Fuentes-Davila and G.P. Hettel, eds., Update on Karnal Bunt Research in Mexico. CIMMYT Wheat Special Report No. 7a.

Rajaram, S., G. Fuentes-Davila, M. van Ginkel, G. Getinet, M. Camacho, J. Montoya, A. Amaya, J. Peña, He Zhong Hu, and C. Tianyou. 1992. Breeding bread wheat resistant to Karnal bunt (*Tilletia indica*). In pages 14-15, G. Fuentes-Davila and G.P. Hettel, eds., Update on Karnal Bunt Research in Mexico. CIMMYT Wheat Special Report No. 7a.

Chapter 7.

Bread Wheat Breeding in the Southern Cone of South America

Man Mohan Kohli

Geographic Location and Wheat Production

The Southern Cone Region, which comprises Argentina, Bolivia, Brazil, Chile, Paraguay, and Uruguay, is the major wheat-producing area of South America. Over 8 million hectares of wheat are seeded annually between 15 and 40°S latitude and 45 and 75°W longitude. The elevation where wheat is grown varies from near sea level in Uruguay to over 3000 masl in Bolivia. The total production varies from year to year, but has averaged over 15 million tons annually (Table 7.1). Although the average yield is approximately 25% lower than the world average, there is wide variation in the region from country to country.

From the mega-environment point-of-view, Southern Cone represents very high variability (Table 7.2). Considering that most of the wheat crop in this region is seeded under rainfed conditions, annual precipitation affects production potential significantly. The area under wheat, especially in the nontraditional warm regions of Brazil, Bolivia, and Paraguay has expanded over

Table 7.1. Wheat Production Statistics in Southern Cone Region, 1990-92.

Country	Area (1000 ha)	Yield (kg/ha)	Production (1000 t)
Argentina	4,858	2,097	10,094
Bolivia	93	833	79
Brazil	2,224	1,347	2,951
Chile	503	3,244	1,621
Paraguay	188	1,470	271
Uruguay	166	1,944	335
S. America	8,203	1,916	15,570
World	22,4681	2,526	567,562

Source: FAO Annual Bulletin.

Table 7.2. Wheat mega-environments (MEs) in the Southern Cone region.

Mega-env.	Characteristic	Countries	Est. Area (1000 ha)
ME1A	Optimum	Chl	250
ME2	High Rainfall	Arg, Brz, Chl, Parg, Urg	2750
ME3	Acid Soils	Brz	1700
ME4B	Low Rainfall	Arg, Brz, Bolv, Chl, Parg	5500
ME5A	High Temperature	Arg, Brz, Bolv, Parg	1800
ME8A	Facultative Wheat	Arg, Chl, Urug	2450

the last decade. A large proportion of the wheat area is seeded to soybeans during summer. Erosion, soil degradation, compaction, and diminishing fertility are major crop management problems.

Southern Cone regional wheat breeding program was started in 1979 in order to collaborate with the National Agricultural Research Systems (NARSs) and strengthen their activities in the areas of mutual interests. The rationale behind the regional position was as follows:

- This region represented the largest wheat area in Latin America and yet most countries were net wheat importers.
- Acid soils were considered an immense challenge and the impact of aluminum-tolerant wheats being developed in collaboration with Brazilian NARS needed to be expedited.
- Foliar and spike diseases have been critical here and there was a need to build a better germplasm base for resistance in high-yielding semidwarf wheats.
- Regional NARSs were joining hands with the Inter-American Development Bank (IDB) and the Inter-American Institute of Agricultural Cooperation (IICA) to transfer technology horizontally and wished CIMMYT to provide technical assistance to this effort.
- The percent of poor people, although less than Asia and Africa, constituted a serious concern.
- Since 1986, research support has been essential in developing wheats for nontraditional warm areas to open new frontiers.

General Objectives

CIMMYT's general objectives in the Southern Cone are to:

- Assist NARSs and the CIMMYT base program in generating, selecting, and distributing high yielding germplasm adapted to the region;
- Collaborate and expedite seed multiplication of newly released varieties;
- Identify formal and informal training opportunities for the young wheat scientists of the region;
- Organize institution building activities with NARSs, Regional Networks, CIMMYT, and other institutions.

Specific Objectives

Breeding for abiotic stresses

Warm areas—Nontraditional warm areas are defined by average temperatures that are over 17.5°C during the coolest month (July). Besides high temperature, some of these areas suffer from drought during late tillering and flowering periods. In combination with high humidity, there is serious disease pressure especially by leaf rust, spot blotch, tan spot, and powdery mildew.

Germplasm selection from the base program has been effective. In addition, the crossing program started in Paraguay has led to the identification of specifically adapted, high-yielding germplasm, which is being tested regionally. Average yield increase is calculated to be approximately 1.5% per year.

Improved disease resistance has partially cut down on chemical control, thereby improving profit margins and environmental safety.

Acid soils—Located primarily in Brazil, these soils are highly leached, low in lime and phosphorus and contain toxic levels of aluminum. Besides soil problems, this area suffers from a complex of diseases.

A collaborative program started with several Brazilian institutions has led to an overwhelming supply of new germplasm and high-yielding varieties. Approximately 70% of the varieties released contain one or more parents of CIMMYT origin and about a third of them were selected for one or more generations in Mexico. Alondra, a CIMMYT line, played a key role in developing the new germplasm.

The yield of newly released varieties such as BR35 and EMBRAPA 16 is almost 50% higher in southern state of Rio Grande do Sul, as compared to the yield of IAC 5-Maringa, a standard check for acid soils. A CIMMYT economics study shows yield gains/year to be 3.1% for Rio Grande do Sul and 2.4 and 1.5% for southern and northern regions of Parana state, respectively.

Drought stress—As shown in Table 7.2, a large percentage of the area comes under the winter drought environment, which is associated with predominantly pre-flowering stress. The selection for drought-tolerant germplasm is done primarily in the empirical manner using grain yield under water stressed environments as the base. Other drought resistance-related characters, such as early ground cover, small or folding leaves, and earliness have also been useful, but their individual contribution cannot be quantified.

Several drought-prone locations in Argentina and Bolivia have been identified, but their relative value in selection has varied from year to year. Based on their performance over the years, high yielding varieties such as Seri M 82, Cruz Alta INTA, Klein Chamaco, OCEPAR 16, and Tui'S' have been released in the region.

Breeding for disease resistance

Leaf rust—In general, the region has depended on the germplasm coming from the base program to incorporate leaf rust resistance into local breeding efforts. However, the dynamic changes in the rust population have been able to overcome single gene-based resistance very rapidly. Thus, the resistance conferred by *Lr9*, *Lr24*, and *Lr26* was ineffective in a very short period, which caused withdrawal of several major varieties.

Over the last five years, the regional approach to leaf rust has been to incorporate slow rusting and durable resistance characters conferred by a number of new CIMMYT varieties. In the Paraguayan Program, the resistance of Cordillera 4 (MN72131), probably based on *Lr13+Lr34*, has held for over 15 years. This is being used widely in the local crossing program.

Spot blotch—Spot blotch (*Bipolaris sorokiniana* syn. *Helminthosporium sativum*) is the second most important disease in the nontraditional warm areas. Brazil, Paraguay, and lowland Bolivia suffer from epidemics regularly.

In collaboration with a GTZ-supported project managed by Dr. Y.R. Mehta, IAPAR, Parana, Brazil, a large number of lines are screened each year. This effort led to the identification of the first set of differentials for this disease as well as a large number of superior lines. However, recently developed germplasm based on *Agropyron curvifolium* and Chinese parents has shown tremendous advantage over the earlier germplasm. At present, this resistance is being transferred to the local high yielding

lines and the segregating populations are also being selected for better breadmaking quality and shattering resistance.

Tan spot—Tan spot (*Pyrenophora tritici-repentis*) is a new concern in the region, which is increasing its importance along with the increase in conservation tillage (zero tillage) practices. In some countries such as Uruguay where zero tillage is not common, the role of alternate hosts such as *Lolium* spp. or other grasses is being explored.

The present strategy is based on screening under zero tillage conditions to identify superior sources of resistance. The better lines have been distributed to key locations inside and outside the region such as North Dakota in the USA and Australia to check the stability of resistance. The first group of superior germplasm was tested in 1993 and, based on observations from other locations, this material will be incorporated into the regional breeding effort.

Powdery mildew—Powdery mildew (*Erysiphe graminis* f.sp. *tritici*) is another disease that has gained more importance over the last five years. The reason for the widespread breakdown of powdery mildew resistance is probably related to the ineffectiveness of rye-based resistance in recent years. CIMMYT germplasm containing the 1B/1R substitution and widely adapted to the region has been hit the worse.

The new regional approach to improving powdery mildew resistance is based on: 1) diversification of sources of resistance, 2) evaluation of regional germplasm with regards to genetic variability, and 3) large-scale screening of CIMMYT germplasm at key locations in the region. Besides new bread wheat sources, the resistance from *T. dicoccon* and *Haynaldia villosa* has been incorporated into the crossing program. The regional germplasm based on PM17 (Amigo) and a combination of PM2+PM6 (Itapua35) remain effective. Large-scale testing during 1993 also resulted in the identification of new CIMMYT genetic resources with good levels of resistance, such as Milan, Sitella, Amsel, Alubuc, and Gimpel, etc. As in the case of leaf rust, an effort is being made to identify parents with slow mildewing or durable resistance.

Septoria leaf blotch—The majority of the southern part of the region under the influence of high rainfall suffers from this disease caused by *Septoria tritici*. According to a collection of virulences done in different countries and sent for analysis to Dr. Zahir Eyal in Israel, the region represents the widest variability in the fungus at a global level. Both bread wheat and durum wheat virulences are common in the region, which explains the large percentage of germplasm that is susceptible.

Besides screening for stable sources of resistance, it has been determinhed recently that field evaluations from certain key sites can help select different levels of resistance. The breeding strategy is to utilize these sources in different combinations with the regional germplasm and select lines at La Estanzuela, Uruguay, which represent the highest degree of pathogen variability. Eventually, it will be necessary to study the genetic basis of this type of resistance.

It is interesting to mention that some parents, such as Milan, which have good tan spot resistance, also demonstrate septoria leaf blotch resistance.

Fusarium head blight resistance—The spread of fusarium head blight (scab) in this region is probably as extensive as that of leaf rust. When the disease occurs—usually in in wet years only especially during flowering—it can cause serious yield and quality losses in the wheat crop. Although the

regional breeders have selected low infection varieties such as Frontana, Encruzilhada, Klein Atlas, Tezanos Pintos Precoz, Estanzuela Young, and Itapua 25, their performance in heavy scab years has not always been acceptable. Furthermore, virtually all of these varieties are tall and of lower yield potential than the new improved varieties. As a result, chemical control of scab has been an alternative.

Ever since the appearance of Chinese germplasm with superior scab resistance, it has been used widely to incorporate resistance into the regional germplasm. During a brief period, CIMMYT had assigned a scab pathologist to the region to expedite the development of this new germplasm. Although a large number of advanced lines have been generated in the regional program and tested over locations, they do not show resistance levels equal to those of the parents. In recent years, some Catbird lines, derived from Chinese germplasm, have shown a combination of moderate to high levels of resistance with high yield potential.

The program strategy is to combine Chinese resistance to scab with that of regional sources to widen its scope and also add on adaptation and industrial quality characters. There is a plan in the region to use alternative methods of screening (toxin) to add efficiency to the selection procedure in the segregating populations.

Other diseases—Other diseases present in the region, which have been considered from the screening standpoint, include: stem rust, stripe rust, bacterial stripe, septoria glume blotch, barley yellow dwarf virus, and soilborne mosaic virus. All of these are important in one or more parts of the region. Breeding for resistance is concentrated in specific programs and CIMMYT provides assistance in exchange of germplasm and information in specific cases.

Impact of CIMMYT Collaboration with NARSs

CIMMYT collaboration from the regional program or together with the base program have facilitated the availability of high-yielding germplasm in the NARSs. Data on the varietal releases and yield are presented in Tables 7.3 and 7.4. In a recent study on the impact of introduction of CIMMYT wheat germplasm in Argentina during 1973-90, Dr. Luis Macagno of INTA calculated that the increases yields contributed more than US$900 million to the Argentine economy. The yield increases attributed to the new germplasm in Brazil are also likely to contribute millions of dollars per year to that country's economy. The introduction of high-yielding germplasm in lowland Bolivia and Paraguay, both nontraditional warm

Table 7.3. Contribution of germplasm of CIMMYT origin in wheat varieties and their yield in Southern Cone region

	Varieties released 1984-93			Grain yield (kg/ha)	
Country	Total	Germ. CIMMYT	%	1979-81	1992
Argentina	54	39	72	1547	2222
Bolivia	16	16	100	661	860
Brazil	97	67	68	927	1423
Chile	46	33	72	1711	3379
Paraguay	7	6	86	1226	1600
Uruguay	9	6	67	1341	1734
Total	230	167	73	1315	2013

areas, during the late 1980s and early 1990s represents a savings of approximately US$60 million per year in foreign exchange. Similar figures can be calculated for other countries in the region.

In addition to the yield gains mentioned above, the NARSs of the region have decreased their dependence on fungicides for disease control. The new resistant germplasm has not only increased the profit margins of the farming community, but has also added to environmental safety.

Service to the NARSs in the Region

The collaborative nature of the regional program is achieved by being in permanent contact with the NARSs and in doing whatever is needed to upgrade the national programs. The activities vary from country to country based on the needs and development of each. Many of these activities are not easy to quantify, but aim at achieving realistic objectives in yield and disease resistance. CIMMYT's regional role is that of facilitators and catalyzers. While in some countries, our support is basically collegial, more hands on effort with researchers is required in others. The following set of activities during 1993 summarizes of support to NARSs:

- Annual wheat planning meetings in Bolivia and Paraguay;
- Generation advance in summer nurseries in Bolivia and Chile;
- Planning the crossing program in Paraguay;
- Travelling workshops in Brazil and Uruguay;
- Agronomic/disease observations in all countries;
- Germplasm selection in all countries;
- Regional workshops and meetings in all except Chile;
- Support to PROCISUR activities in all countries.

To accomplish the activities mentioned above, the regional breeder spent 147 days outside of Paraguay in 1993. Such a significant amount of time spent with the NARS also means generation of information and feedback to CIMMYT base.

Besides direct assistance activities, a Regional Advanced Lines Nursery (LACOS) is coordinated annually on behalf of PROCISUR. This nursery represents around 300 lines from 20 national wheat breeding programs. Over 50% of the germplasm in this nursery is from local sources and adds to the genetic variability available to each program. The purpose of this nursery is to circulate regional germplasm among all national programs in the region and key cooperators outside and generate information on adaptation, yield potential and disease resistance in multi location testing. The results are analyzed and published each year. Based on the results of this nursery, several lines have been released in individual countries and lines or varieties have moved from one country to another.

Table 7.4. Effect of shuttle breeding on the development of wheat varieties in Brazil, 1984-93.

	Soils	
Breeding results	**Acid**	**Non-Acid**
Total varieties released	73	24
Varieties from Brazilian crosses	63	1
Varieties from CIMMYT crosses	10	23
Varieties with all Brazilian selections	50	2
Varieties with one or more CIMMYT selections	23	22
Varieties carrying CIMMYT progenitor in cross	43	24

Chapter 8.

Bread Wheat Breeding in the Dryland Areas of West Asia and North Africa

G. Ortiz Ferrara

Introduction

Nearly one-third of the area planted to bread wheat in developing countries is located in marginal environments characterized by frequent drought stress during the growing season (Byerlee and Morris 1993). Although marginal environments are widely distributed across the developing world, most of these areas are concentrated in West Asia and North Africa (WANA).

In WANA, bread wheat production depends largely on rainfall during the growing season. This crop is the principal food source for a majority of the population, which, on average, consumes more than 145 kg/year per capita, the highest consumption in the world.

The environments where bread wheat is grown in WANA are characterized as highly variable and unpredictable in terms of rainfall (amount and distribution), temperature, soils, and diseases and insect pests (Ortiz Ferrara et al. 1987). Faced with such large variations in climate, weather, and stresses in the dryland areas of the region, the CIMMYT/ICARDA Bread Wheat Improvement Program at Aleppo, Syria, places special emphasis on developing cultivars suitable to these marginal environments.

The breeding strategies used by the Program have been published elsewhere (Ortiz Ferrara et al. 1987, 1989; Ortiz Ferrara and Deghaiz 1988). The Program focuses its research on breeding and identifying parental material that possesses high grain yield and stability, with tolerance to abiotic stresses such as terminal drought, cold, and terminal heat, and resistance to biotic stresses such as yellow rust, septoria, common bunt, sawflies, Hessian flies, sunni bugs, and aphids.

Attention is given to developing and verifying breeding methodologies. The single-seed descent method of selection is used to complement our efforts in breeding for specific qualitative traits such as yellow rust and Hessian fly; and the modified bulk to enhance adaptation. Multilocation selection/testing and targeting of germplasm have proved to be useful selection strategies, and continued emphasis is placed in the selective exploitation and use of exotic material including landraces. All these activities have resulted in an enhanced adaptation of bread wheat germplasm and of material being adopted increasingly by NARSs, particularly those in mega-environment 4 (ME4A, low-rainfall temperate).

This paper defines the target environment and clientele in WANA, lists the research priorities in the Program, describes the breeding methodology for the dryland areas of the region, and presents some of the modest but significant achievements obtained so far. The future plans in the operational activities of the Program are also discussed.

Target Environment/Clientele

WANA is comprised of 24 countries with more than 300 million people. Wheat and barley are the dominant crops and occupy more than 42 million hectares annually. In WANA, bread wheat is grown in three different agroclimatological zones based on moisture availability and temperature regimes. These are:

- Areas of low rainfall associated with low temperatures (LRT, annual rainfall <400 mm);
- Areas of moderate rainfall with moderate to high temperatures (MRT, annual rainfall between 400-600 mm);
- Irrigated areas (IRR).

The area and percentage of bread and durum wheat grown in the low rainfall areas of WANA and in the developing world are presented in Table 8.1. Because the total area planted to bread wheat is much larger than that planted to durum wheat, in absolute terms, the area planted to bread wheat in marginal environments is much larger than the area planted to durum wheat in such environments. During the mid-1980s, countries in WANA planted approximately 12.5 million hectares of bread wheat in the low-rainfall areas, equivalent to about 63% of the total bread wheat area grown in the region (Byerlee and Morris 1993).

Research results confirm that the region's semi-arid rainfed sites (less than 400 mm), where most of the bread wheat is grown, are more dissimilar and variable in terms of moisture availability and temperature than the sites with adequate moisture supplies (more than 400 mm or irrigated; Table 8.2). The semi-arid, low temperature rainfed sites are characterized by a longer maturity duration, shorter plant height, and lower grain yield when compared to the mild winter, adequate moisture sites. The greater standard deviation for the four agronomic characters tested in the semi-arid rainfed sites is a reflection of the greater variability in moisture availability and temperature among the semi-arid rainfed vs. adequate moisture sites. Variability in plant height and grain yield is greatly affected by rainfall and temperature variability, and variability in maturity duration is greatly affected by fluctuation in winter temperature.

Table 8.1. Area (million hectares) and percentage of bread wheat and durum in the low-rainfall zones in the developing world during the mid-1980s.

Region	LRBW BW area	% of total	LRDW DW area	% of total
WANA	12.5	63	5.9	74
South Asia	6.8	23	1.5	94
East Asia	4.7	16	0.0	0
South America	4.5	50	0.1	16
Developing countries total	28.5	32	7.5	72

LRBW = Low rainfall bread wheat; LRDW = Low rainfall durum wheat.
Source: Byerlee and Morris (1993).

Research Priorities

The list of research priorities within the bread wheat Program for each of the three agroecological zones in WANA are presented in Table 8.3. The low rainfall environments of the region (less than 400 mm) receive highest priority.

Breeding Methodology

The long-term objectives of the CIMMYT/ICARDA bread wheat improvement Program continues to be the development of germplasm that has the following attributes:

- Increased and stable yield under varied amounts and distribution of rainfall;
- Abiotic stress tolerance: terminal drought, cold, terminal heat, and salt;
- Resistance to diseases: the three rusts, Septoria, bunts, etc.;
- Resistance to insect pests: sawfly, Hessian fly, Sunni bug, and aphids;
- Acceptable nutritional and industrial quality;
- Development of improved agronomic practices with national programs in the region;
- Training.

High yield and yield stability over years in the rainfed environments, which are important characteristics needed in the region, are derived through application of the following strategies:

- Continuous evaluation of potential parents;
- Targeted crosses;
- Multilocation selection and testing;
- Targeted distribution of improved germplasm to NARSs in WANA.

The philosophy behind this approach reflects the Program's interest in improving yield stability by developing cultivars that perform well across diverse environments. Of course, within this breeding context, the program emphasizes site-specific breeding activities. The orientation of these special

Table 8.2. Summary statistics for rainfed semi-arid and adequate moisture sites in WANA for four plant response variables.[a]

	Semi arid (<400 mm)		Adequate moisture (>400 mm & irrigated)		All sites	
Variable	Mean	SD	Mean	SD	Mean	SD
Grain yield (kg/ha)	3693	2108	4256	1655	3916	1944
Days to heading	127	32	89	16	112	27
Days to maturity	168	28	133	18	154	25
Plant height (cm)	83	18	96	13	89	16
Sample size	32		21		53	

[a] Based on trial means from RWYT 1983-84 and 1984-85.
** Significant difference between rainfed and adequate moisture sites (P<0.01).

efforts, however, is always towards overcoming one or more limiting environmental factors by incorporating into widely adapted germplasm the specific genetic traits needed to improve performance in certain locations, i.e., drought and cold tolerance, disease resistance, insect pest tolerance, etc.

Targeted F1 single and top crosses are made every year and segregating populations from F2 to F8 are grown and evaluated at Tel Hadya and Breda (dry site) under both favorable and stress conditions. Favorable conditions include early planting (early October), 100 kg N/ha and 60 kg P_2O_5/ha, and two supplementary irrigations, simulating 400 mm overall rainfall for germination and disease enhancement. Stress conditions include low rainfall (200-300 mm) and low fertilizer rates (40 kg N/ha and 40 kg P_2O_5/ha). These segregating populations are also tested for diseases and insect pests in other locations in Lebanon and Syria.

Table 8.3. List of research priorities in the CIMMYT/ICARDA bread wheat improvement program (1983-93).

	Production zone		
Research activity Priority	**LRT (<400 mm)**	**MRT (400-600 mm)**	**IRR**
Breeding			
Yield	****	***	*
Yield stability	****	***	*
Stresses			
Terminal drought	****	***	*
Cold	****	**	*
Heat	**	***	***
Salinity	*	**	*
Methodology			
Selection methods	****	***	*
Multilocation testing	****	****	***
Strategies	****	***	*
Pathology			
Foliar diseases	*	***	***
Seedborne diseases	***	**	*
Entomology			
Insect pests	****	***	*
Agronomy	**	**	*
Physiology	***	**	*
Quality			
Breadmaking	****	***	*
Nutritional	****	***	*
Training	****	***	*
Regional activities	****	****	****

LRT= Low rainfall-low temperature areas; MRT= Moderate rainfall with moderate to high temperature areas; IRR= Irrigated areas. Priority: * Low; ** Medium; *** High; **** Very High.

The program emphasizes multilocation testing of early segregating material, which is done with a modified bulk method of selection in the F2 generation. Plants are individually selected in each of the most desirable F2 crosses, then bulked within each cross. The resulting F3 bulk families are evaluated for disease resistance and overall agronomic performance in five "hot spots" in the region. Undesirable families/plants are then discarded early in the segregating phase. Quality information on these F3 bulk families is also used in the selection process. From F3 to F7, individual plant selection is used and replicated yield testing of advanced lines starts with the F6 to F8 generations.

Prior to distribution to NARSs, promising lines are yield-tested in preliminary trials over 2 years and three sites in Syria. The most promising lines are promoted to advanced yield trials over 1 or 2 years in five environments in Lebanon and Syria with a long-term annual average rainfall gradient of 250-600 mm.

Information on disease and insect pest resistance is collected as soon as lines are bulked for preliminary yield testing. When the lines are promoted to advanced testing, multilocation information on disease resistance is obtained from the Key Location Disease Nursery (KLDN). Promising lines are then promoted to international nurseries for distribution and testing at about 75 locations in the region.

Achievements and Progress

The present breeding methodology has resulted in an enhanced adaptation of bread wheat germplasm and of material being adopted increasingly by NARSs, particularly those in the dryland, low-rainfall environments in WANA. Highlights of these achievements are presented in the following sections.

Germplasm development and distribution

In collaboration with NARSS staff in WANA, a number of improved genetic stocks have been identified. These have desirable traits and are made available as parental material to NARSs for use in their breeding programs.

Table 8.4 gives the number and attributes of bread wheat lines that have been identified and distributed to NARSs in WANA during the last 7 years (1987-93). More than 1,200 genetic stocks have been sent. They are distributed as crossing blocks to decentralize our breeding activities to national programs so they can generate new sources of genetic variability.

In addition to these gene pools and other improved, semi-finished germplasm, the bread wheat program has also been distributing early segregating populations (F2s and F3s) to NARSs in WANA. This operation started in 1979 with the

Table 8.4. Number of bread wheat lines with desirable genetic traits distributed to national programs as genetic stocks during the last seven years, 1987 to 1993.

Genetic traits	Average no. per year	Total
High yield and stability	37	259
Abiotic stress resistance		
Terminal drought	24	168
Cold	12	84
Terminal heat	14	98
Biotic stress resistance		
Yellow rust	15	105
Leaf rust	10	70
Stem rust	5	35
Septoria leaf blotch	12	84
Common bunt	10	70
Wheat stem sawfly	15	105
Hessian fly	3	21
Selected landraces	7	49
Breadmaking quality	9	63
Total	1211	

objectives of 1) providing increased genetic variability and 2) allowing national programs to select breeding material under their own local conditions.

Table 8.5 lists the number of F2 and F3 segregating populations that have been distributed to NARSs in WANA, and the number of locations where these crosses have been tested during the last 11 years (1983-93). More than 6000 crosses have been distributed to 391 location-years within the region. The experience obtained so far is that most NARSs have released more varieties from directly introduced, semi-finished material than from early segregating populations. This trend is in agreement with results that have been documented in a recent survey analysis carried out by CIMMYT (Byerlee and Moya 1993). Research infrastructure, budget availability, and overall strength of NARSs are the main factors accounting for these differences.

Enhancing disease resistance

Disease resistance is important in the adaptation of germplasm in the rainfed areas of the WANA. The Program emphasizes multilocation testing of early segregating material using a modified bulk method of selection for disease resistance. Details of this methodology are described by Ortiz Ferrara and Deghaiz (1988). Further information is collected when selected lines are bulked for preliminary yield testing.

Table 8.6 presents the progress made by the program in enhancing the disease levels during the last 8 years (1983-91). Data of the CIMMYT/ICARDA bread wheat observation nurseries show that substantial progress has been made in raising the level of resistance to the three rusts. More emphasis has been placed lately to incorporate additional sources of resistance to septoria leaf blotch. With pathology assistance, several hundred crosses have been made with resistant gene pools, including germplasm from the former Soviet Union, South America, and CIMMYT/Mexico.

Enhancing abiotic stress resistance

Terminal drought, cold, and terminal heat are the main abiotic stresses responsible for reduced yields in the rainfed, Mediterranean environments of WANA. Using the breeding methodology described before, a number of bread wheat lines have been identified as higher yielding than the local and improved checks in four different environments in Syria and Lebanon (Table 8.7). A large number of genotypes were found superior to the local check (Mexipak 65) than to the improved checks Cham 4 and Cham 6. Cham 6, a commercial variety released for the low-rainfall (250-350 mm) areas of Syria, is more difficult to beat in the drier environment of Breda. Cham 4, released for the irrigated and high rainfall areas of the country, shows better performance under the optimum environment Terbol. These four environments play an important role in identifying germplasm with multiple abiotic stress resistance. Cham 4 and Cham 6 have also been released in other countries in the region (Table 8.8).

Table 8.5. Early segregating populations distributed to national programs in WANA during the last 11 years, 1983 to 1993.

	No. of accessions		Total	No. of locations	
Year	F2	F3		F2	F3
1983	150	-	150	32	-
1984	150	918	1068	30	6
1985	150	600	750	15	7
1986	87	126	213	50	6
1987	150	425	575	26	6
1988	128	455	583	26	6
1989	102	155	257	29	5
1990	120	848	968	30	6
1991	116	471	587	30	6
1992	122	362	484	25	5
1993	135	350	485	40	5
Total	1410	4710	6120	333	58

Enhancing germplasm adaptation

Improved germplasm is distributed, taking in account local agroclimatic conditions, to NARSs in WANA upon request. Two objectives when distributing germplasm are: 1) providing promising lines for potential release as commercial varieties, and 2) collecting information on adaptation. Multilocation

Table 8.6. Progress made during the last eight years (1983-91) in increasing the levels of resistance to certain foliar diseases in the bread wheat germplasm.

	No. of entries*								
	YR		LR		SR		ST		
ACI Class	1983	1991	1983	1991	1983	1991	1983	1991	ST Class
0-5	21	73	16	65	29	59	0	2	1
6-10	10	29	12	46	20	45	3	5	2
11-15	12	10	13	9	10	9	16	28	3
16-20	17	8	18	5	19	10	21	32	4
21-25	14	1	20	3	12	1	49	52	5
26-30	17	5	16	0	15	1	27	8	6
31-35	19	0	19	0	2	2	15	0	7
36-40	8	0	9	0	3	0	3	1	8
>40	18	3	13	1	26	2	2	1	9

ACI = Average coefficient of infection; ST = Septoria tritici;
YR = Yellow rust; SR = Stem rust; LR = Leaf rust.
* = Wheat observation nurseries.

Table 8.7. Number and percentage of bread wheat lines yielding higher than the local and improved checks in different stressed environments in Syria and Lebanon, AWYT's 1992 and 1993.

		Checks							
		Mexipak		Cham4		Cham6		All three checks	
Environment	Year	No.	%	No.	%	No.	%	No.	%
Terminal drought (Breda)	1992	122	46	130	49	30	11	15	6
	1993	159	63	138	55	28	11	18	7
	Mean	141	55	134	52	29	11	17	7
Cold (TH-EP)	1992	229	87	94	36	65	25	54	20
	1993	218	86	43	17	68	27	38	15
	Mean	224	87	69	27	67	26	46	18
Terminal heat (TH-LP)	1992	208	79	195	74	61	23	50	19
	1993	203	80	111	44	55	22	46	18
	Mean	206	80	153	59	58	23	48	19
High input (Terbol)	1992	93	35	97	37	159	60	58	22
	1993	126	50	55	22	110	44	48	19
	Mean	110	43	76	29	135	52	53	21

N=264 (1992), N=252 (1993); TH-EP= Tel Hadya early planting;
TH-LP= Tel Hadya late planting.

Table 8.8. Bread wheat varieties released or currently under extensive testing (*) in countries of WANA during the last 12 years (1982-94). Names in boldface indicate germplasm distributed by CIMMYT/ICARDA.

Country	Year of release	Variety
Algeria	1982	Setif 82, HD 1220
	1989	**Zidane 89**
	1992	**Nesser**, ACSAD 59, **Zidi Okba**, Rhumel, 21 AD, Soummam
Egypt	1982	Giza 160
	1988	Sakha 92, Giza 162, Giza 163, Giza 164
	1991	Gemmeiza 1, Giza 165
Ethiopia	1984	Dashen, Batu, Gara
Iran	1986	Golestan, Azadi
	1988	Sabalan, Darab, Quds
	1989	Falat
	1994 (*)	**F 134-71/Crow, Prl/Pew**
Jordan	1988	Jubeiha, Rabba
	1992	**Nesser**
Lebanon	1990	Seri 82
	1992	**Nesser**
	1994 (*)	**Chorizo, Ghurab-2, Memof-2**
Libya	1985	Zellaf, Sheba, Germa
	1994 (*)	**Cham 4**
Morocco	1984	Jouda, Merchouche
	1986	Saada
	1989	Saba, Kanz
	1994 (*)	**Shuha-1, NS732/Her**
Oman	1987	**Wadi Quriyat 151, Wadi Quriyat 160**
Pakistan	1986	Sutlej 86
Qatar	1988	**Doha 88**
Sudan	1985	**Debeira**
	1987	Wadi El Nil
	1991	Neelain
	1992	Sasarieb
	1994 (*)	**Nesser, Flk/Hork**
Syria	1984	**Cham 2**, Bohouth 2
	1986	**Cham 4**
	1987	Bohouth 4
	1991	**Cham 6**, Bohouth 6
	1994 (*)	**Gomam, Chorizo, Ghurab-2**
Tunisia	1987	Byrsa, Salambo
	1992	Vaga 92
Turkey	1987	**Dogankent-1**
	1988	Kaklic 88, Kop, Dogu 88
	1989	Es14
	1990	Yuregir, Karasu 90, Katia 1
U.A.E.	1990	**Cham 2**
Yemen	1983	**Ahgaf**, Marib 1
	1988	**SW/83/2**, Mukhtar, Aziz, Dhumran

testing and targeting of germplasm has increased adaptation of materials in the region, particularly in the low-rainfall environments.

Table 8.9 gives the yields of six promising bread wheat lines in the dry areas of WANA. The 13 locations in West Asia and three in North Africa were characterized by having low rainfall (<350 mm). These lines were selected by those NARSs for further national testing and/or for use in their breeding programs as parents possessing high yield and good adaptation.

Wheat germplasm adoption

Before they can have any impact on cereal production, improved cultivars must reach farmers. To assist in this, we collaborate with NARSs in conducting on-farm trials in Syria, Algeria, Sudan, Lebanon, Morocco, Tunisia, and Egypt. As a result of this collaboration, cooperators in WANA have identified outstanding lines from the regional yield trials sent by the joint CIMMYT/ICARDA program for on-farm verification, large scale testing, and possible release as commercial varieties.

Table 8.8 lists examples of bread wheat varieties released or currently under extensive testing in countries of WANA during the last 12 years (1982-1994).

Table 8.9. Mean relative yield (MRY), rank (R) and standard deviation (SD) of the top yielding entries in West Asia (*) and North Africa (**); RWYT-LRA 1991-92.

Cross and pedigree	MRY	R	SD
West Asia			
Gomam SWM 11619-2AP-4AP-1AP-2AP-0AP	1.101	1	.149
Inia/RL4220//7C/3/Yr'S'/5/12300..... ICW80-0745-4AP-1AP-3AP-0AP	1.067	2	.119
Tr 380-16-3A614/Chat'S' CM 64868-1AP-1AP-3AP-1AP-3AP-0AP	1.052	3	.168
Mean yield (kg/ha)	2846	-	-
No. of locations	13	-	-
North Africa			
Tr 380-16-3A614/Chat'S' CM 64868-1AP-1AP-3AP-1AP-3AP-0AP	1.186	1	.358
Venac-1 CM 67404-7AP-1AP-3AP-0AP	1.147	2	.406
Vehyk CM 78045-06AP-300AP-3AP-300L-0AP	1.111	3	.283
Mean yield (kg/ha)	2625	-	-
No. of locations	3	-	-

MRY = Entry yield divided by trial mean yield and then averaged over trials; * = Afghanistan, Iraq, Syria, Turkey and Lebanon; ** = Algeria, Morocco and Tunisia.

An adoption study conducted in Syria by the Farm Resource Management Program (FRMP) of ICARDA during 1991 showed that, modern high-yielding varieties (HYVs) account for 87% of the area planted and are grown by 86% of the farmers surveyed (Tutwiler and Mazid 1991).

Since 1983, the Syrian National Program has released six improved bread wheat varieties. These are: Bohouth 2, 4, and 6; and Cham 2, 4, and 6. The amount of seed produced by the Government Organization for Seed Multiplication (GOSM) of Syria for these varieties are presented in Table 8.10. Assuming a seed rate of 150 kg/ha, these varieties occupied approximately 241,000 ha during the 1992-93 crop season and about 200,000 ha during 1993-94. These figures are rather conservative considering that most farmers in Syria retain their own seed for the next crop cycle. During the last two years, GOSM has reduced the amount of seed produced of Mexipak 65 (local variety), while Cham 4, an improved CIMMYT/ICARDA cultivar has become the leading variety grown by farmers. The data in Table 8.10 support the findings of the adoption study carried out by the FRMP of ICARDA.

Four years of collaboration with the National Program of Algeria in conducting joint on-farm verification trials has resulted in the release of three CIMMYT/ICARDA bread wheat varieties: Zidane 89, Zidi Okba, and Nesser (Table 8.8). On average, these varieties were reported to yield, respectively, 97, 80, and 87% more than the local check Mahon Demiaz under farmers' field conditions, at three dry locations in West Algeria.

There are approximately 250,000 ha of wheat in the dry areas of West Algeria (Tiaret and Sidi Bel Abbes). Farmers there have already adopted these three varieties. Table 8.11 presents results of the IFAD/IDGC/ICARDA Technology Transfer Project conducted in Western Algeria. It compares differences between local and improved released varieties of bread wheat with durum wheat and barley in farmers' fields (FS) and on research stations (OSS). The three bread wheat varieties substantially overyielded the local check under OSS. Only Nesser, a variety released in Syria for the less than 300-mm areas maintained its yield superiority under FS. Table 8.11 also shows the advantages bread wheat varieties have over the durum and barley cultivars under those harsh conditions.

Table 8.10. Bread wheat varieties and amount of seed produced by the Government Organization for Seed Multiplication (GOSM) of Syria, and distributed to farmers during 1992 and 1993.

			Seed quantity (tons)			
Variety		Year	1992	1993	Total	%, I>L
Mexipak 65	(L)	1969	5500	-	5500	100
Cham 2	(I)	1984	-	-	-	-
Bohouth 2	(I)	1984	-	-	-	-
Cham 4	(I)	1986	16500	14400	30900	562
Bohouth 4	(I)	1987	10000	9500	19500	355
Cham 6	(I)	1991	4000	4600	8600	156
Bohouth 6	(I)	1991	175	200	375	7
Total			36175	28700	64875	

L = Local; I = Improved; YR = Year of release.

Future Plans

The future plans (1994-2000) are summarized in Table 8.12. The Program will further emphasize its research efforts targeted for the low-rainfall and temperate areas of WANA. It will discontinue those activities carried out in the optimum moisture environments of the region (i.e., high-rainfall and irrigated areas). Certain activities in the moderate rainfall areas, as highlighted in Table 8.12, will continue to receive attention. The distribution of improved germplasm to NARSs in WANA will be adjusted accordingly and special priority will be given to the low-rainfall areas of the region.

References

Byerlee, D., and M. Morris. 1993. Research for marginal environments: Are we underinvested?. Food Policy, October 1993, pp: 381-393.

Byerlee, D., and P. Moya, P. 1993. Impacts of international wheat breeding research in the developing world, 1966-1990. Mexico, D.F.: CIMMYT. 135 pages.

Maatougui, M.E.H. 1992. Highlights on activities and achievements. IFAD/IDGC/ICARDA Technology Transfer Project. Sidi Bel Abbes, Algeria. 50 pages.

Ortiz Ferrara, G., D. Mulitze, and S.K. Yau. 1987. Bread wheat breeding for tolerance to thermal stresses occurring in West Asia and North Africa. In pages 267-282, E. Acevedo, E. Fereres, C. Gimenez, J.P. Srivastava, eds., Improvement and Management of Winter Cereals under Temperature, Drought and Salinity Stresses. National Institute of Agricultural Research (INIA), Madrid, Spain.

Table 8.11. Comparative differences between local and improved-released varieties of bread wheat, durum, and barley within farmer's and on-station sites in Western Algeria, 1991-92 (Modified from Maatougui 1992).

	Grain yield (kg/ha)				
Varieties	**FS(a)**	**I>L**	**OSS(a)**	**I>L**	**OSS-FS**
Bread wheat					
Mahon Demiaz (L)	1765	-	1869	-	104
Zidi Okba (I)	1450	-315	2064	195	614
Nesser (I)	2450	685	2255	386 -	195
Zidane 89 (I)	-	-	2341	472*	-
Durum wheat					
Owed Zenati (L)	1310	-	1419	-	109
Waha (I)	1735	425	1927	508*	192
Kebir (I)	-	-	2390	971*	-
Barley					
Saida 183 (L)	1550	-	1085	- -	465
Rihane (I)	1750	200	1699	614	-051
Badia (I)	-	-	1430	345 -	
WI 2269 (I)	-	-	1297	212 -	
No. of sites	2	2	3	35	

I = Improved; L = Local; FS = Farmers' site; OSS = On-station site;
* = Significantly different (P<0.05); (a)=Plot size 0.5 ha

Ortiz Ferrara, G., and M. Deghaiz, M. 1988. Modified bulk: A selection method for enhancing disease resistance and adaptation in rainfed wheat. In pages 1149-1153, Proceedings of the Seventh International Wheat Genetics Symposium, Cambridge, England.

Ortiz Ferrara, G., S.K. Yau, and M.A. Mousa. 1989. Identification of agronomic traits associated with yield under stress conditions. In pages 67-88, Physiology-Breeding of Winter Cereals for Stressed Mediterranean Environments (Montpellier, France, 3-6 July 1989). INRA, Paris 1991 (Les Colloques No. 55).

Tutwiler, R., and A. Mazid. 1991. Impact of modern wheat technology in Syria. Part one: The adoption of new technologies. Farm Resource Management Program: Annual Report 1991. ICARDA, pp. 176-209.

Table 8.12. List of research priorities in the CIMMYT/ICARDA bread wheat improvement program (1994-2000).

Research activity	Production zone		
Priority	LRT (<400 mm)	MRT (400-600 mm)	IRR
Breeding			
Yield	****	*	D
Yield stability	****	*	D
Stresses			
Terminal drought	****	D	D
Cold	****	D	D
Heat	***	D	D
Salinity	D	D	D
Methodology			
Selection methods	****	*	D
Multilocation testing	****	*	D
Strategies	****	*	D
Pathology			
Foliar diseases	*	***	D
Seed borne diseases	***	D	D
Entomology			
Insect pests	****	D	D
Agronomy	***	D	D
Physiology	****	D	D
Quality			
Bread making	****	*	D
Nutritional	****	*	D
Training	****	**	D
Regional activities	****	****	****

LRT = Low rainfall-low temperature areas; MRT= Moderate rainfall with moderate to high temperature areas; IRR= Irrigated areas. Priority: * = low; ** = medium; *** = high; **** = very high. D = Discontinued.

Chapter 9.

Winter Bread Wheat Breeding and Zinc Deficiency

Hans-Joachim Braun

Introduction

The Government of Turkey and CIMMYT signed an agreement in 1986 to initiate the International Winter Wheat Improvement Program (IWWIP). The objective of this collaborative project is to develop winter wheat germplasm for developing countries, in particular for West Asia and North Africa (WANA).

During the last 20 years and in particular during initial phase of the IWWIP, several thousand wheat cultivars were introduced to Turkey from winter wheat breeding programs all around the world, especially from programs in the Pacific Northwest and the Great Plains of the US, Eastern Europe (Romania, Hungary, Bulgaria, Croatia, and Serbia), China, and CIMMYT/Mexico. These cultivars were tested for their adaptation to the Central Anatolian Plateau of Turkey and it was hoped to identify some outstanding lines that could be directly released as varieties. However, only a few introductions, e.g., Bolal from Nebraska, were grown over large-scale rainfed areas. The other widely grown cultivar, Bezostaya from Russia, is mainly grown on more fertile soils or is irrigated. The general lack of adaptation of wheat genotypes to the Central Anatolian Plateau of Turkey (CAP) indicated that there may exist unrecognized factors which limited the performance of introduced cultivars to CAP. E.E. Saari (pers. comm.) suggested in 1988 that high levels of boron in the soil may be one such factor. While boron toxic soils are present on CAP, boron toxicity could not explain all the problems observed. The author, based on observations made in Eskisehir in 1989, suggested that zinc deficiency may cause the leaf necrosis. In 1990, trials related to Zn-deficiency in cereal production were initiated by the Agricultural Research Institute in Eskisehir. Since then, zinc deficiency has been confirmed as an important factor for limiting cereal production on the Central Plateau through further surveys and trials.

Interestingly, in agricultural literature reviews on the occurrence of zinc deficiency in cereal production, none of the WANA countries are mentioned. This does not necessarily mean that Zn deficiency does not occur in WANA. Based on a variety of information sources, including FAO soil surveys (Sillanpää 1982), soil maps, germplasm performance, information received from colleagues, and personal observation, it is likely that Zn deficiency may also occur in the following countries: Afghanistan, Egypt, Iran, Iraq, Kirgizistan, and Syria. For other WANA countries, except Lebanon, where zinc deficiency is not likely to occur, no information was available regarding the zinc status of the soils. In order to obtain more information regarding the importance of micronutrient disorders, several cereal cultivars (identified by R. Graham, Waite Institute, Adelaide, Australia) known for their efficient or inefficient response to nutrient disorders ("bio-indicators") were added to the FAWWON, a wheat observation nursery,which is distributed to more than 100 cooperators throughout WANA and the world.

Aggravating the identification of zinc deficiency in WANA countries is that very few or only one cereal cultivar covers the total arable area. For example, in Turkey one winter barley and one winter durum cultivar cover 95% of the total area devoted to these crops, and 70% of the rainfed winter wheat area is

covered by less than five cultivars. In Iran, one winter wheat cultivar covers nearly the total rainfed winter wheat area. Therefore, comparisons between cultivars in farmers' fields are very difficult. Furthermore, these cultivars are most likely well adapted to such nutrient stress conditions and deficiency or toxicity symptoms are normally not well pronounced. For example, the Turkish winter barley variety Tokak is among the most boron tolerant barleys ever tested at the Waite Institute, Adelaide, Australia (A. Rathjen, pers. comm.)

Differences among wheat cultivars were first observed on the new breeding station of the Agricultural Research Institute in Eskisehir. The local check, Gerek 79, showed significantly better performance than other entries in 1989 when a dry spring made zinc deficiency symptoms particularly obvious. An application of 60 kg $ZnSO_4$ increased the yield of bread wheat, durum wheat, and barley between 50 and 60% (Figure 9.1).

Frequently, yield and protein content of wheat cultivars grown on the CAP are lower than what is expected, considering N application, agronomic practices, climate, and breeders' estimates based on phenotypic scores. The effect of 60 kg $ZnSO_4$ and N fertilizer on yield of bread wheat, durum wheat, and barley cultivars are shown in Figure 9.2. The formulation in which N was applied (NH_4SO_4 or NH_4NO_3) did not affect yield. However, the addition of Zn doubled the yield in the case of bread wheat and durum wheat. Barley showed a much less significant response to zinc treatment. This is in agreement with previous observations and suggest that barley is more tolerant to zinc deficiency than bread wheat or durum. In the field where the trial was conducted, cereal cyst nematodes (CCN, Heterodera avenae) were also identified. Since Barley is more tolerant to CCN than wheat, at least part of the yield differences may be due to presence of CCN.

Zinc deficiency as a problem for wheat production on the CAP was only identified in 1989. One reason may be that during the last decade Turkish farmers changed to higher concentrated phosphate fertilizers.

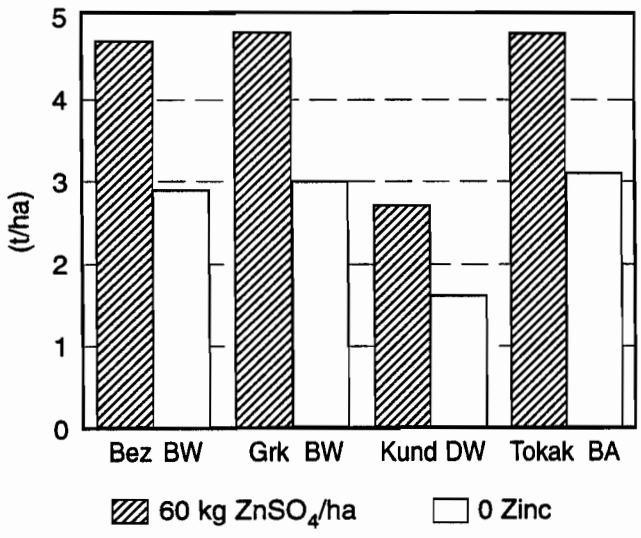


Figure 9.1: Yield response of two bread wheats, one durum wheat, and one barley Variety to 60 kg $ZnSO_4$ application in Eskisehir 1992 (Data from M. Kalayci.)

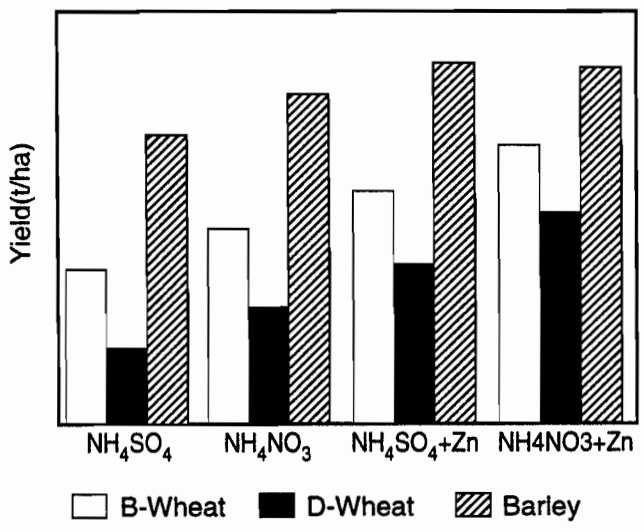


Figure 9.2: Mean grain yield response of three bread wheats, (Gerek, Bolal, and Ki one durum wheat (Kunduru), and one barley cultivar (Cumhuriyet) to 60 kg / and 60 kg / ha $ZnSO_4$-fertilizer. Data from M. Kalayci, Eskisehir ARI.

Such phosphate fertilizers do not contain zinc as contamination. However, there has been an unconscious selection for zinc efficiency by Turkish cereal breeders over the years (Table 9.1). The positive correlations between yield and zinc content in leaves confirm that zinc content in leaves is a good parameter to measure the zinc efficiency of wheat cultivars.

Breeding for Zinc Efficiency

Significant yield increases due to zinc application suggest that zinc fertilizer should be applied on a routine basis by Turkish farmers. However, there are points in favor of breeding wheat cultivars with increased zinc efficiency and increased zinc content in the grain. Some of these arguments as well as possible benefits from such cultivars for Turkey and most likely other WANA countries are discussed below.

Zinc deficiency in top and subsoils

Zinc deficiency in Turkey occurs both in top and subsoils. Under such circumstances, zinc fertilizer incorporation though the soil profile is very difficult and only roots in the top 20 cm benefit from zinc application. However, during drought periods, roots in upper portion of the soil profile account for only a minor fraction of the nutrient and water uptake. Especially in years with severe droughts, zinc deficiency symptoms are most pronounced. In pot experiments, Nable and Webb (1993) showed that, under such conditions, the zinc-inefficient wheat cultivar Gatcher extracted more water from the subsoil when zinc was supplied to the subsoil. By contrast, the water uptake of the zinc-efficient wheat cultivar Excalibur increased only marginally and its grain yield was higher than that of Gatcher under all conditions (Table 9.2).

Table 9.1: Effect zinc application (60 kg $ZnSO_4$ / ha) on leaf concentrations of Zn and grain yield of three Turkish bread wheat cultivars, one introduced cultivar (Atay 85), one durum wheat and two barley cultivars[a] in Eskisehir.

		Zn-concentration (ppm)		Grain Yield (kg/ha)	
Cultivar		**-Zn**	**+Zn**	**-Zn**	**+Zn**
Kirac	(BW)	7.9	12.2	1911	2477
Gerek 79	(BW)	8.5	11.1	1739	2273
Yayla 305	(BW)	7.4	12.6	1733	2424
Atay 85	(BW)	6.4	10.2	1495	2127
Kunduru	(DW)	7.4	15.1	1149	1821
Tokak	(BA)	7.8	17.6	2940	3197
Cumhuriyet	(BA)	6.4c	18.9a	3037	3159

Correlation between yield and leaf Zn-concentration for bread wheat
n=13 r:[-Zn]: Yield=0.64*
r:[+Zn]: Yield=0.74**

[a] Barley yields on the Central Anatolian Plateau are generally higher than wheat yield. One reason may be that barley in more tolerant to Cereal Cyst Nematodes than bread wheat. In soil samples from this experiment 40 cysts / 250 cm^3 soil were counted.

Table 9.2: The effect of subsoil zinc treatment and genotypic zinc efficiency on yield and removal of water from the subsoil by wheat cultivars in deep pots in the glasshouse (Nable and Webb 1993.)

Cultivar and water regime	Grain Yield (g/pot)	Water use (liter/pot)
Gatcher (Zn-inefficient)		
Zn supplied to top 10 cm	23	9.1
Zn supplied to top and subsoil	29	10.3
Excalibur (Zn-efficient)		
Zn supplied to top 10 cm	33	9.4
Zn supplied to top and subsoil	34	9.6

Disease resistance

Zinc is involved in more than 300 enzymes. Cakmak and Marschner (1988a) observed that zinc deficiency in cotton increased root exudation of K^+, amino acids, sugars, and phenolics by a factor of at least 2.5 and concluded that zinc plays a major role in maintaining the membrane integrity. This enhanced leakage of organic and inorganic solutes in Zn-deficient plants is explained by Marschner and Cakmak (1988b,c) due to increased peroxidative damage to biomembranes by 0_2-. The major role of zinc in membranes seems to be related to the protection of the membrane lipids and proteins from peroxidation. This leakage of solutes may explain why zinc-deficient wheat plants are more susceptible to fungal root diseases such as *Fusarium graminearum* (Sparrow and Graham 1988) and *Rhizoctonia solani* (Thongbai et al. 1993). The leakage creates a favorable environment for the fungus and, due to the damaged membranes, increases the susceptibility of the plant for these diseases. All cases investigated so far have shown that the deficiency predisposes the plant to infection rather than the infection causing the deficiency (Graham and Welch 1994). This observation is of particular interest for Turkey and other WANA countries, since evidence is growing that root diseases have been either ignored in the past or are recently becoming more important.

Sections of a zinc-deficient bean leaf were protected from direct sun light. In this area, no chlorosis was observed. If solar radiation increases due to an increasing ozone hole, zinc efficiency may become a very important trait in areas with high radiation.

Wheat plants showing zinc deficiency symptoms in fields on the CAP were frequently infected by CCN (Lung 1993a). CCN can penetrate cereal roots only through root tips and they move actively to this location. It is known that an organic substance, most probably amino-acids, lead the nematodes to the root tips. Since cereals grown on iron- or zinc-deficient soils can enhance uptake of these elements through release of phytosiderophores (PS, nonproteinic amino acids; Roehmheld and Marschner 1990), it was speculated that PS may attract CCN. This was confirmed in following laboratory tests. Lung (1993b) found an attractivity factor of 0.8 of PS on CCN.

Cakmak et al. (1994) suggested that enhanced release of PS under zinc deficiency may be at least partly responsible for the efficiency of some cultivars to mobilize zinc under such conditions. Consequently, such zinc-efficient wheat genotypes would also be highly attractive for CCN. If this assumption is correct and if future nematode surveys confirm the preliminary observations, that CCN are widespread on the CAP and occur in numbers high enough to cause a grain yield reduction, breeding of CCN resistant wheat cultivars becomes a necessity. Nematicide application is not an alternative, since it is very expensive and dangerous. The nematicide Temek® is not released for application to cereals in Turkey.

Seedling vigor and seed quality

Seeding rates are very high in many WANA countries. Farmers on the CAP of Turkey use a seeding rate of 200-300 kg/ha, which is three to six times as high as in countries with similar climate. Seeding rate trials in Turkey have shown, that seeding rates below 150 kg/ha cause a yield reduction. There is, at present, no explanation why such high seeding rates are needed. Rengel and Graham (unpubl.) found that zinc content in seeds is positively correlated with seedling vigor. Most farmers on the CAP produce their own seed. Since soils on the CAP are often zinc-deficient, it is most likely that the zinc content of the grain is low. Seedlings from such seeds may be more susceptible to diseases and consequent winterkill. At present, the interaction between seeding rate, zinc application, and nematode damage is being investigated. The return from this research could be tremendous. If the seeding rate could be reduced by 80 kg/ha, Turkish farmers on the CAP could save around 400,000 t of seed with a value of $US80,000,000.

Bioavailability of zinc

Based on the available knowledge, breeding for zinc efficiency has a very high priority in the IWWIP. At present, we are not aware of any negative genetic linkage between zinc efficiency or high zinc content in the grain and other traits of interest. Rather, it appears that zinc plays such an important role in plants (and humans), that only positive effects can be expected from breeding zinc-efficient cultivars.

So far, all arguments mentioned to breed for wheat cultivars with an increased zinc efficiency or increased zinc content in the grain have been related to production increase. Zinc deficiency in humans has been reported in Turkey and Iran. Cereals are the main component of the diet of these populations, where up to 70% of the daily energy uptake comes from bread. The zinc status of populations, which have such a cereal based diet, could be improved if the bioavailability of zinc in cereals could be increased.

The negative effect of local bread (unleavened whole grain bread) on zinc absorption is shown in Figure 9.3 (Cadvar, 1993, unpublished). Zinc absorption was around four times higher in the diet without bread.

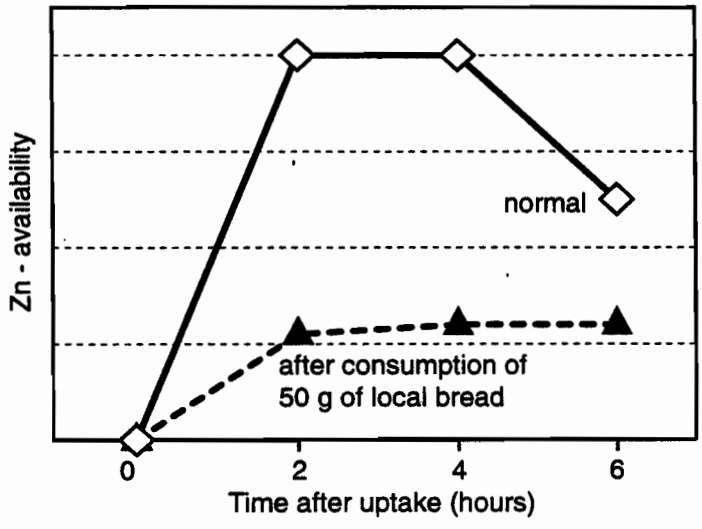


Figure 9.3: Schematic uptake rate of 50 mg Zinc sulfate after a normal diet and after consumption of 50 g of local bread. Sample size: 7 healthy men. (Cavdar, pers. comm.)

It has to be stressed that the bread consumption of villagers is not 50 g, but in the range of 500 to 800 g/day. Such local bread has a high phytin and fiber content, which reduce the bioavailability of zinc. If the absolute zinc content in wheat grains is the limiting factor for the zinc bioavailability, then breeding for an increased zinc content in the grain will improve bioavailability in any case, assuming the phytin content does not increase too. The latter should be possible. As mentioned before, the phytin content is a function of plant-available P in the soil. Since high levels of P can induce zinc deficiency, the P-status of zinc-deficient soils should be monitored well and excessive P fertilization should be avoided.

The author does not know what genetic variability exists regarding phytase activity. However, since the phytase activity is heavily affected by the breadmaking process, chances to improve zinc bioavailability by changing phytase activity does not seem to be high. Rather, it seems feasible to increase the phytase activity by changing the breadmaking process, e.g., loaf bread, as it is consumed in Turkish cities, has a higher bioavailability of zinc than unleavened whole grain bread, even though the zinc content in leaf bread is much lower (Reinhold et al. 1976).

Grahan and Welch (1994) discuss the importance of promoters, mostly organic acids and amino acids, for the bioavailability of zinc. From a breeding point-of-view, increasing the content of promoters, which serve as catalysts, looks very attractive, since marginal increases are likely to have large effects of zinc bioavailability. This is important since the minor changes in the promoter content are not likely to have negative effects on the food quality. This is in contrast for breeding for a lower antinutrient content (see above), which is most likely to have negative effects on food quality due their potential anticarcinogenic and antimutant function.

Some of these questions will be addressed in a NATO-funded project under the leadership of Dr. Cakmak from the Cukurova University in Adana in collaboration with the Turkish Ministry of Agriculture, the Medical Faculty of the Ankara University, Agricultural Faculty of the Harran University and CIMMYT. The objective of the project is to select and characterize cereal genotypes with high resistance to Zinc deficiency and Boron toxicity and to evaluate the bioavailability of Zinc in cereals for the GAP (SSE-Turkey) and the CAP.

Zinc deficiency in humans in Turkey

The importance of breeding for an increased bioavailability of zinc in Turkey had been demonstrated by the research team of Prof. Ayhan Cavdar from the Medical Faculty of the Ankara University. Cavdar has worked during the last 30 years on topics related to zinc deficiency in humans. Her experience is best summarized by the following quotation: "Not only Fe-deficiency, but also zinc deficiency is of importance to public health in Turkey" (Cadvar et al. 1983). This statement is based on the following observations (Cadvar et al. 1983):

- Nutritional status of villagers is poor:
  - Wheat products are dominant in their diet.
  - Low bioavailability of zinc due to high phytin and fiber content of cereals.
  - Low meat consumption.
  - Absolute amount of zinc in diet is low.
- Pica = habit of eating soil clay:
  - Observed in 42 of 67 Turkish provinces.
  - Mainly observed among children and women.
- Pica causes iron and zinc deficiency through:
  - Reduced appetite.
  - Clay reduces zinc and iron absorption.
- Long term zinc deficiency may cause irreversible changes in intestinal epithelial cells which account for malabsorption of zinc and iron.

Symptoms and diseases related to zinc deficiency in humans

Based on Cavdar's data on Turkish patients, there is strong evidence that the following symptoms and diseases are related or caused by zinc deficiency: Growth retardation and a delayed or no sexual maturation (Cadvar et al. 1983). The rate of anencephaly[1] cases in Turkey is high compared with other countries and is in the range of 2 to 2.6/1000 deliveries. All data had been collected in major cities (Cadvar et al. 1988, Akar et al. 1991). It is possible that the rate is higher in rural areas, since zinc deficiency may be more frequent there (see above) due to Pica and unbalanced diets. It studies the zinc serum content of mothers with anencephalytic babies was significantly lower compared to a control group of mothers with healthy babies. That malnutrition plays an important role in these cases is supported by the fact that nearly all mothers with anencephalytic babies were of lower socioeconomic status.

Further evidence for the relation between zinc status and anencephaly was provided by a case, in which a mother who had two ancephalytic babies then delivered a healthy boy (Cadvar et al. 1991). Before and until the sixth month of her third pregnancy she had been treated with $ZnSO_4$.

Other symptoms, based on observations made on Turkish patients, which are related to zinc deficiency include the negative effect on the immune system and Hodgkins disease. At present, 3 children/month are diagnosed with HD in Ankara (A. Cadvar, pers. comm.). Most HD patients have chronic zinc deficiency and are of lower socioeconomic status. Cadvar has suggested that zinc deficiency may prepare a mileu favoring development of Hodkins disease. Chronic zinc deficiency was also found in patients suffering from Mediterranean Anaemia, Thalassemia major, a disease caused by a genetic disorder (Cadvar et al. 1990).

Conclusions

Zinc deficiency symptoms in humans in Turkey have been reported since 1967. Zinc deficiency as a constraint for cereal production on the CAP has only been recognized since 1989. At present, there is no information available that zinc efficiency in bread wheat is negatively linked with other traits of importance. Rather, it appears that zinc plays such an important role in plants (and humans) that only positive effects can be expected from breeding zinc-efficient cultivars. The chances for high monetary return from such research are very high. The feasibility to increase the bioavailability of zinc in cereals has to be investigated. If the bioavailability can be increased, positive effects on the zinc nutrition status of humans, in particular women and children in villages, are likely to occur.

Acknowledgments

Information presented in this paper was obtained from Dr. I. Cakmak, Cukurova University, Adana; Prof. A. Cadvar, Ankara Unviersity; F. Eyupoglu, Soil and Fertilizer Inst., Ankara; M. Kalayci, AARI, Eskisehir; Dr. G. Lung, University of Hohenheim, Germany; Dr. A.R. Rathjen, Waite Inst., Adelaide; Australia.

[1] Anencephaletic babies are borne with an open spine. Only parts of the brain are developed. They are normally stillborne or die within few days after birth.

References

Akar, N., M. Bahcesi, D. Uckan, N. Dincer, H. Yavuz, and A.O. Cavdar. 1991. Maternal plasma zinc levels after oral zinc tolerance test in pregnancies associated with neural tube defect in Turkey. J. Thrace Elements in Exp. Med. 4:225-227.

Cakmak I., and H. Marschner. 1988a. Increase in membrane permeability and exudation in roots of Zn deficient plants. J. Plant Phys. 132:356-361.

Cakmak, I., and H. Marschner. 1988b. Zinc-dependant changes in ESR signals, NADPH oxiydase and plasma membrane permeability in cotton roots. Physiol. Plant. 73, 132-186.

Cakmak, I., and H. Marschner. 1988c. Enhanced superoxide radical production in roots of zinc deficient plants. J. Exp. Bot. 39:1449-1460.

Cakmak, I., K.Y. Gülüt, H. Marschner, and R.D. Grahan. 1994. Effect of zinc and iron deficiency on phtyosiderophore release in wheat genotypes differing in zinc efficiency. J. Plant Nutr. In press.

Cavdar, A.O., A. Arcasoy, S. Cin, E. Babacan, and S. Gözdasoglu, 1983. Geophagia in Turkey: Iron and zinc absorption studies and response treatment with zinc in geophagia cases. In: Zinc deficiency in Human Subjects. P. 71-97. Allan R. Liss, Inc., New York.

Cavdar, A.O., M. Bahcesi, N. Akar, J. Erten, G. Bahceci, E. Babacan, A. Arcasoy, and H. Yavuz. 1988. Zinc status in pregnancy and the occurrence of anencephaly in Turkey.

Cavdar, A.O., E. Unal, S. Cin, and B. Kologlu. 1990. Somatomedin C and Zinc status in betha-Thalassemia Major. In : Six Cooley's Anemia Symp. Vol. 612 of the Annals of the NY Academy of Sci.

Cavdar, A.O., M. Bahceci, N. Akar, J. Erten, and H. Yavuz. 1991. Effect of zinc supplementation in a Turkish women with two previous anencephaletic babies. Gynecol Obstet. Invest. 32:123-125.

Eyüboglu, F. 1994. Tukiye topraklarinin bitkiye yayayisli mikro element durum. Project No. 620/A-002. TOPRAKSU, MARA.

Fitzgerald, S.L, R.S. Gibson, J.Q. de Serrano, L.P.A. Vasquez, E. de Zepada, C. Lopez-Palacios, L.U. Thompson, A.M. Stephen, and N.W. Solomons. 1993. Trace element intakes and dietary phytate/Zn and Ca x phytate/Zn millimolar ratios or periurban Guatemalan women during the third trimester of pregnancy. Am. J. Clin. Nutr. 57:195-201.

Graham, R.D., and R.M. Welch. 1994. Breeding for staple-food crops with high micronutrient density. Long-term sustainable agricultural solutions to hidden hunger in developing countries. Paper presented at the organizational workshop for "Food policy and agricultural technology to improve diet quality and nutrition", organized by IFPRI in Annapolis, Jan. 10-12. 1994.

Lung, G. 1993a. Report about the distribution of nematodes on cereals in Central Anatolia, Turkey. Inst. of Phytomed., Dep. of Nematology, University of Hohenheim, Germany.

Lung, G. 1993b. The role of phytosiderophores as an attractive substance of root exudates from several cereals for second stage juveniles of Heterodera avenae. *Paper presented at the Int. Phytopath. Conf., Montreal.*

Michael, B., F. Zink, and H.J. Lantzsch. 1980. Effect of phosphate application on phytin-phosphorus and other phosphate fractions in developing wheat grains. Z. Pfanzenern, Bodenkde. 143 (4):369-376.

Nable, R.O., and M.J. Webb. 1993. Response of two wheat genotypes to low subsoil zinc supply. Plant Soil (in press).

Raboy, V., S.J. Hudson, and D. Dickson. 1985. Reduced phytic acid does not have an adverse effect on germination of soybean seeds. Plant. Physiol. 79:323-325.

Reinhold, J.G., B. Faradaji, P. Abadi, and F. Ismail-Belgi. 1976. Decreased absorption of calcium, magnesium, zinc and phosphorus by humans due to increased fibre and phosphorus consumption as wheat bread. J. Nutr. 106:493-503.

Röhmheld, V., and H. Marschner. 1990. Genotypical differences among graminaceous species in release of phytosiderophores and uptake of iron phytosiderophores. Plant Soil 123:147-153.

Sillanpää, M. 1982. Micronutrients and the nutrient status of soils. A global study. FAO Soils Bulletin No. 48.

Sparrow, D.H., and R.D. Graham. 1988. Susceptibility of zinc-deficient wheat plants to colonization by Fusarium graminearum *Schw. group 1. Plant Soil 112:261-266.*

Thongbai, P., R.J. Hannam, R.D. Graham, and M.J. Webb. 1993. Zn nutrition and Rhizoctonia root rot of cereals. Plant soil. In press.

Chapter 10.

Durum Wheat Breeding at CIMMYT

Osman S. Abdalla

Introduction

Durum wheat, *Triticum durum* Desf., is cultivated on approximately 17 million hectares worldwide. About half of this area is in developing countries where it is the main staple food and covers greater portion of total wheat area (Abdalla et al. 1992). Durum wheat (DW) production is concentrated in the Middle East, North Africa, the Asian Subcontinent, and Mediterranean Europe. Other production areas include Ethiopia, Argentina, Chile, and the Andean Region of South America as well as Mexico, the United States, and Canada .

DW productivity in developing countries is generally low. This may be attributed to the fact that the crop is raised under low inputs, in semi-arid regions, and other marginal areas characterized by sharp annual fluctuations in cropping conditions. Under irrigated and high rainfall environments where moisture and other resources are not limiting, higher yield levels, approaching or surpassing bread wheat, are obtained. Favorable environments represent a small portion (28.2%) of total DW area. However, about half of the total DW production comes from favorable environments (Byerlee 1992).

At CIMMYT, intensive improvement of DW has been conducted for just over two decades. The efforts of CIMMYT's DW section in collaboration with national programs have led to remarkable improvement in DW productivity. In this presentation, the objectives and breeding methodology of DW breeding at CIMMYT are outlined. Breeding accomplishments relating to yield potential, adaptability and stability, drought tolerance, disease resistance, and improved grain quality are reviewed. Release and adoption of improved DW varieties in developing countries are described and future challenges in DW improvement are discussed.

History of Durum Wheat Improvement in Mexico

The groundwork for CIMMYT's DW improvement program was laid in the 1950s by CIMMYT's predecessor organization (the Office of Special Studies within the Mexican Ministry of Agriculture and Rockefeller Foundation). The objective of the program then was mainly to address the problems of DW production in Mexico. Thus, high priorities were given to introduction of dwarfing genes, elimination of photoperiod sensitivity, improvement of floral fertility, and enhancing disease resistance levels. Emphasis up to the late 1970s was directed mainly to irrigated subtropical environments. Problems of high rainfall areas, drylands, and grain quality issues were first addressed in the 1980s.

Current durum breeding at CIMMYT

CIMMYT's main goal is to assist developing countries in increasing durum productivity by supplying high yielding, widely adapted, disease-resistant germplasm with good end-use quality characteristics. To achieve these objectives, CIMMYT directs breeding efforts to address production constraints encountered in the four mega-environments shown in Table 10.1. The mega-environment (ME) concept was developed by CIMMYT

in the 1980s. Initially, all wheat growing areas of the developing world were grouped into seven MEs (Rajaram and Fischer 1989) and strategies were set to deal with production problems in these agro-ecological zones. By 1993, the number of MEs had evolved to 12 as listed in Chapter 1.

The success of the CIMMYT Durum Program may be attributed to its breeding philosophy and methodology. Through dynamic breeding involving directed and broadly based crossing, shuttle breeding, and multilocation testing, CIMMYT has been able to provide developing countries with high yielding, management-responsive, and input-efficient germplasm. Such basic germplasm has been utilized, and released as varieties worldwide. Table 10.2 lists the main DW nurseries.

Table 10.2. CIMMYT durum wheat nurseries.

Segregating populations
F2 (SXS) Bulk
F2 (SXW) Bulk
Screening nurseries
IDSN—Optimum environments
IDSN—Dryland environments
IDSN—High rainfall environments
Yield trials
Elite Durum Yield Trial (EDYT) OE (ME1)
Elite Durum Yield Trial (EDYT) DL (ME4)
International Durum Yield Nursery (IDYN)

Achievements and Progress

Yield potential and stability

Figure 10.1 shows three years average of yield potential, biomass and harvest index of the varieties released in Mexico since the foundation of CIMMYT to date. Yields have increased from 5.70 t/ha as in "Chapala 67" to 8.97 t/ha in "Aconchi 89". In CIANO 1989/90 cycle, "Aconchi 89" demonstrated a yield potential of 9.6 t/ha.

Table 10.1. Durum wheat mega-environments.

ME/Climate	Major diseases	Representative locations
Spring type		
ME1, irrigated, low rainfall, temperate	LR,YR,PM,SR	Yaqui Valley (Mexico, (Pakistan), Gangetic Valley (India), Nile Valley (Egypt)
ME2, high rainfall, temperate	LR,ST,YR,PM, SR,BYD,Bact,Scab	Mediterranean Basin, Southern Cone, Andean Highlands, East African Highlands
ME4A, low rainfall, temperate, winter rain	ST,YR,LR	Aleppo (Syria), Settat (Morocco)
ME4C, low rainfall, warm	SR	Indore (India)
Facultative type		
ME9, moderate cold, low rainfall	Bunts	Diyarbakir (Turkey)

Note: YR = Stripe rust (*Puccinia striiformis*)
LR = Leaf rust (*Puccinia recondita*)
SR = Stem rust (*Puccinia graminis*)
ST = *Septoria tritici* (*Mycosphaerella graminicola*)
Scab = *Fusarium* spp.
PM - Powdery mildew (*Erysiphe graminis*)
BYD = Barley yellow dwarf luteovirus
Bact = *Xanthomonas translucens*

A number of new advance DW lines have demonstrated yields higher than "Aconchi 89". For the period 1978-1991, the percent yield increase of newly developed high yielding cultivars (HYVs) over the widely grown variety "Yavaros 79" (= Bittern'S') in optimum environment yield trials is presented in Figure 10.2. The observed yield increases represent an increment of about 1% per year. Thus, over the years DW yield potential demonstrated slow but steady increase.

DW grain yield improvements were based on increased grain number/m^2 due to more grains per spikelet (Waddington et al. 1987). Progressive increases in DW yield potential have been associated with increased biomass as well as improved harvest index (Figure 10.1). Further yield advances, however, are expected by increasing harvest index from its current levels.

In Figure 10.3, mean yield of the top five CIMMYT durums at each site of the 20th Elite Durum Yield Trial (EDYT) is expressed as a percentage of the local check yield. Local checks represent site specific adaptations. With the exception of only seven locations out of 47, the top five CIMMYT durums yielded more than the locally adapted checks. These results indicate that CIMMYT has been successful in providing national programs with high-yielding germplasm with potential of release as varieties in their respective environment.

A common feature in many CIMMYT advanced DW lines is the combination of high yield potential and stability—and as a consequence, wide adaptation. Such features have led to the release of CIMMYT germplasm as varieties in

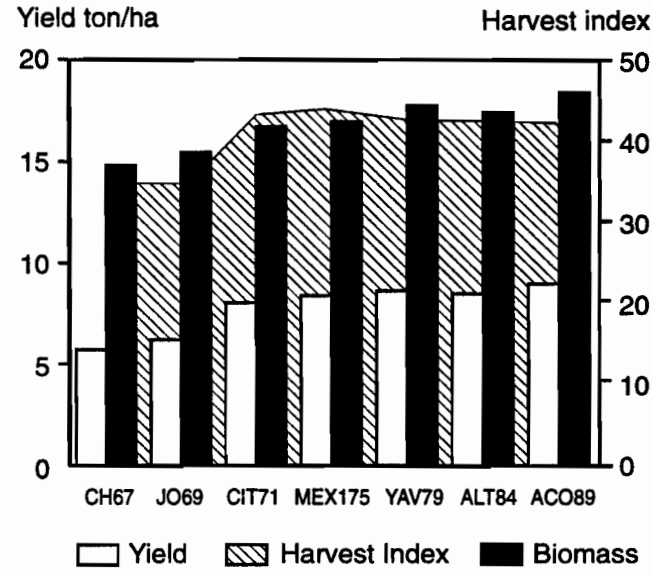


Figure 10.1 Durum wheat yield potential in an optimum environment.

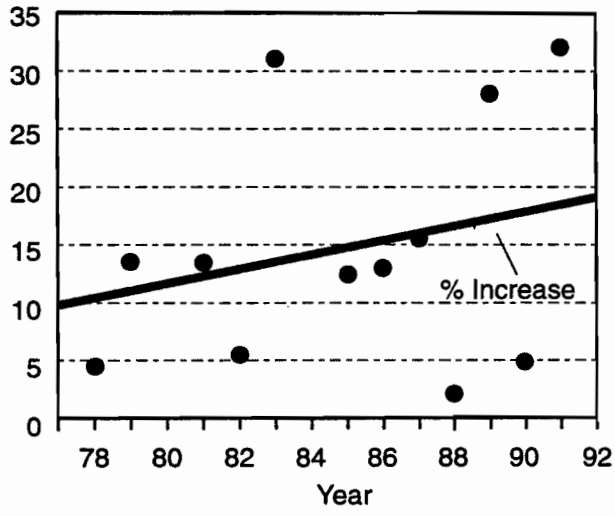


Figure 10.2 Yield increase of HYVs over Yavaros 79 (1987-91 period)

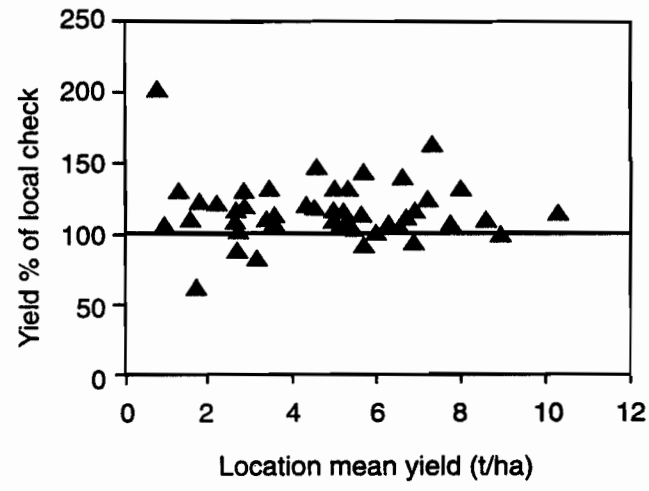


Figure 10.3 Mean performance of the top five CIMMYT DW lines relative to the local check in the 20th EDYT.

many developing countries. Table 10.3 summarizes DW varietal releases in developing countries for the period 1966-1992. From a total of 140 varieties released, 90 varieties (64%) are from CIMMYT crosses. Three CIMMYT-derived DW cultivars, "Cisne", "Frigate", and "Bittern", covered an area of 1.34 million hectares in developing countries during the 1990-91 season (Byerlee 1992).

Drought tolerance

Breeding work for semi-arid environments is conducted in collaboration with the International Center for Agricultural Research in the Dry Areas (ICARDA). CIMMYT's methodology to identify drought tolerant germplasm involves identification of parents based on performance in dryland sites followed by breeding and selection under reduced irrigation in the Yaqui Valley, northwestern Mexico, with alternating summer generations in the sandy soil, drought-prone site of Huamantla in central Mexico. In addition, a line-source or gradient irrigation system, as described by Hanks et al. (1976), was utilized to identify yield stability under varying moisture stress conditions.

Despite the difficulties of breeding for semi-arid conditions, notable progress has been made in developing germplasm for semi-arid conditions. Table 10.4 shows the performance of advanced durum lines compared to the drought-tolerant line Omrabi-5. Under reduced irrigation (a total of 200 mm), yields as high as 2.8 t/ha were obtained, representing a 17% increase over the dryland check. The new generation of DW dryland lines include: "Yazi", "Nehama", "Buttah", "Anade", "Afuwan", "Vips", "Atina", "Pods", and "Shah".

Table 10.3. DW varietal releases in developing countries (1966-1992).

	Releases	
Region	Total	CIMMYT/ICARDA and CIMMYT Crosses
Sub-Saharan Africa	9	4
WANAana	82	52
Asia	22	9
Latin America	27	25
Total	140	90

Source: Byerlee (1992).

Table 10.4. Outstanding lines under reduced irrigation, CIANO, 1989-90.

	Yield	
Genotype	t/ha	% of Omrabi15
QFN/KILL	2.783	117
WIZZA	2.883	117
STN'S'/GOTE'S'	2.535	107

Other encouraging results came from analyzing the 18th Elite Durum Wheat Yield Trial (CIMMYT 1992). Cluster analysis resulted in grouping Yaqui (Mexico), reduced irrigation yield testing site with known semi-arid locations such as Jubeiha (Jordan), Diyarbakir (Turkey), and Tel Hadya (Syria). These results implied that these locations represent similar selection environment.

Disease resistance

One of the major limitations to increased durum wheat cultivation has been unsatisfactory levels of disease resistance. The major diseases of common occurrence in durum growing areas are stem, leaf, and stripe rusts, septoria blotch, head scab, tan spot, powdery mildew, and bunts. In addition, two insects, Hessian fly and sawfly, are serious pests on DW in North Africa and the Middle East.

The multiple resistance approach for the major pathogens in a given ME has been adopted. In this strategy, lines selected for a specific ME should compile many resistance genes for the multiple diseases present in the target environment.

Artificial field inoculation with virulent cultures is routinely practiced in CIMMYT's plots. In addition, many disease hot spots in Mexico and internationally are utilized to expose DW advance lines to various pathogen populations/races. Another CIMMYT approach to build up genetic resistance is the establishment of specific shuttle programs with certain disease hot spots outside of Mexico that have known diverse and virulent pathogen populations, e.g., stem rust shuttle with Ethiopia.

Identified sources of resistance from international screening as well as landraces and known resistance sources from the CIMMYT Wheat Germplasm Bank are utilized in the crossing program. Interspecific and intergeneric crosses are also made to transfer resistance to durum wheats.

Progress has been made in improving the level of disease resistance in CIMMYT's durum wheats. Achievements in improving stem, leaf, and rust resistance are described below:.

Stem rust resistance—In most DW growing areas, with the exception of Ethiopia, an adequate level of stem rust resistance is available in CIMMYT germplasm. The combination of resistance genes present in most CIMMYT durums appears to be ineffective in Ethiopia (Singh et al. 1992). In 1984, CIMMYT initiated a collaborative program with the DW research team at Debre Zeit Agricultural Research Experiment Station of Alemaya University. The main objectives of the program were to produce agronomically superior germplasm with high yield potential and enhanced genetic diversity for stem rust resistance.

This collaborative effort is continuing and has already started to show dividends. During the 1987-88 cycle, only 3% of the advanced lines tested at Debre Zeit were found to be resistant to the prevalent races of stem rust. By 1989-90, 20% of the lines were resistant, in addition to having high yield and good agronomic type. In the 1991-92 cycle, 15% of the tested lines combined stem rust and bacterial blight resistance. Despite of recent success in Ethiopia, that led to the release of the new cultivars "Foka" and "Kilinto" in 1992 and 1993, respectively, more efforts are needed to deal with stem rust problem in East Africa. Currently, genetic diversity is being enhanced by incorporating Sr2 from `Iumillo' and Sr2 and Sr13 from Khapli emmer and other unknown resistance genes from Ethiopian DW landraces.

Leaf rust resistance—Intensive efforts went into enhancing the leaf rust resistance level in CIMMYT's germplasm. On international testing, CIMMYT advance DW lines generally displayed adequate level of resistance. Table 10.5 summarizes the progress made in improving leaf rust resistance in CIMMYT germplasm. The frequency of lines that have resistance equal or superior to "Altar 84" has increased from 5% in the 16th IDSN (1984-85) to 28% in the 22nd IDSN (1990-91). "Altar 84" which carries three additive genes display very low rust severity in Mexico and elsewhere. Singh et al. (1993) believe that this combination of additive genes not only confers very effective resistance, but also is of durable nature. The data presented show that the level of resistance has been constantly up-graded and implied more resistance factors have been accumulated in the newer germplasm.

Stripe rust resistance—Similar efforts were made to improve stripe rust resistance level in CIMMYT durum wheat germplasm. Table 10.6 demonstrates the progress made in up-grading stripe rust resistance. In recent nurseries, the frequency of lines with high level of stripe rust resistance is increasing.

Improved grain quality

The importance of durum wheat as basic food is well established for most of the countries of North and East Africa and the Near and Middle East. It is also important in the Asian Subcontinent and the Andean Region of South America.

Durum grain is used to prepare various products in different parts of the world. The acceptability of a new DW variety is greatly influenced by its quality characteristics. DW products generally require large vitreous kernels with high protein, good yellow pigment and strong to medium-strong gluten. Thus, the incorporation of quality characters essential for end-use products is a major objective in DW breeding at CIMMYT. The recent advances made in improving DW quality at CIMMYT are reflected in the progenitors utilized in crossing, the specialized durum quality nurseries (DQN) and the germplasm distributed to the national programs and cooperators.

Table 10.5. Improvement of leaf rust resistance in CIMMYT germplasm.

		Infection range (ACI)	Altar 84 Score (ACI)	No. lines equal to Altar 84	No. lines superior to Altar 84	% lines > Altar 84
16th IDSN 1984-85:						
No. Entries	No. Loc.					
155	10	2.8-39.0	4.8	0	7	5%
20th IDSN 1988-89:						
No. Entries	No. Loc.					
243	13	0.0-17.6	0.1	12	8	8%
21st IDSN 1989-90:						
No. Entries	No. Loc.					
198	6	0.3-32.3	1.8	2	33	18%
22nd IDSN 1990-91:						
Loc.Entries	No. Loc.					
158	16	0.7-26.1	3.8	2	43	28%

ACI = Average coefficient of infection.

Table 10.6. Improvement of stripe rust resistance in CIMMYT DW Germplasm.

		Infection range (ACI)	Best check score	No. lines equal to best check	No. lines superior to best check	% Lines ≥ best Chk
15th IDSN 1983-84:						
No. Entries	No. Loc.					
264	6	0.0-36.4	2.5	0	42	16%
21st IDSN 1989-90:						
No. Entries	No. Loc.					
198	6	0.0-32.8	2.2	9	32	21%
22nd IDSN 1990-91:						
No. Entries	No. Loc.					
158	5	0.0-21.5	2.0	8	45	34%

ACI = Average coefficient of infection.

Table 10.7 shows the frequency of low molecular weight (LMW) glutenin subunits, LMW-1 and LMW-2, in the most recently analyzed DW crossing block (CBSDW-BV92). Examples of varieties or advance lines carrying the respective subunits are given. Ninety-four percent of the total entries of the crossing block carry LMW-2, which is associated with strong gluten (Payne et al. 1984). The remaining 6% are resistance or tolerance sources for particular diseases or stresses rather than quality.

Figure 10.4 exhibits gluten strength frequency distribution in CIMMYT's current crossing block (CBSDW-BV93) and indicates the gluten strength of known check varieties and popular crosses. Observed gluten strength based on SDS-Sedimentation values, ranged from 5.0 to 18.0 cc. The figure shows that 59% of the total entries in the crossing block have higher sedimentation values, i.e., better gluten quality than the strong gluten cultivar "Don87=Don Pedro". In contrast, the frequency distribution of yellow pigment in the current crossing block (CBSDW-BV93) shows only 4% of the lines have better pigment than "Don87". This implies more effort is needed to upgrade the level of yellow pigment in CIMMYT germplasm.

To enhance specific quality parameters in CIMMYT-derived germplasm, specialized durum quality nurseries (DQN) are used by the Mexico-based CIMMYT DW program. Table 10.8 shows the ranges

Table 10.7. Frequency of low molecular weight (LMW) glutenin subunits in the DW crossing block (BV92).

Glutenin subunit	Frequency	Example, variety or line
LMW-1	6%	Immer; Sla; Chelle; Waha
LMW-2	94%	Cit-71; Mexi75; Yav79; Don87

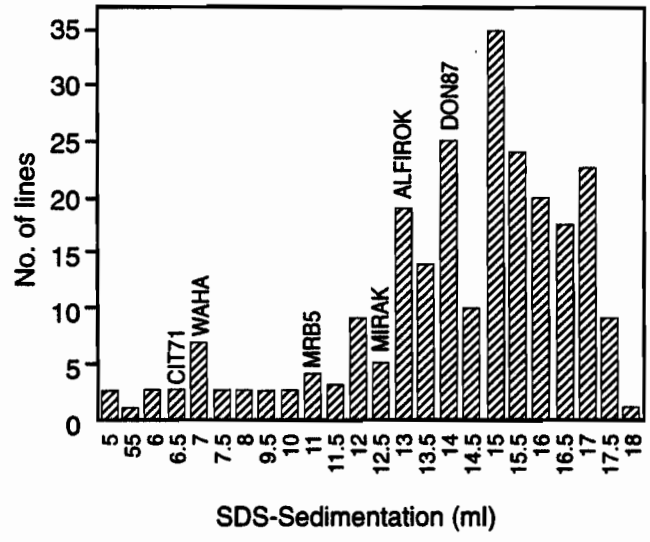


Figure 10.4. Frequency distribution of crossing block lines (BV-93) based on SDS-Sedimentation test.

Table 10.8. Specialized international DW quality nurseries and their quality parameters.

		Protein %		Yellow Pigment(ppm)		SDS sedim. (ml)	
Nursery	Total no.	Range	Mean	Range	Mean	Range	Mean
PC Protein	20	13.5-17.8	14.3	—	—	—	—
PC Pigment	13	—	—	10.4-12.0	11.0	—	—
PC Sedimentation	43	—	—	—		15.0-17.5	15.5
PC Sedim + Pigm	21	—	—	8.6-13.2	9.8	14.0-16.5	15.0

SDS Sedim. = Gluten quality parameter.

and means of quality parameters of the specialized nurseries. The quality characteristics of some advance DW lines from specialized DQNs are presented in Table 10.9 and compared to known varieties. The data shows quality superiority of DQN lines over current varieties.

As a result of emphasizing quality lately, marked improvement is witnessed in the quality of germplasm distributed recently to national programs and cooperators. Figure 10.5 compares gluten strength distribution frequencies in the 20th, 23rd, and 25th International Durum Screening Nursery (IDSN). The figure shows that the frequency of weak gluten has been greatly reduced over the years and that of strong gluten has increased. These results indicate that, in recent years, CIMMYT has produced and distributed a greater number of lines with superior quality to national programs.

With observed increases in productivity and the approach of self-sufficiency, quality is expected to be, more than ever, an important consideration in germplasm acceptability. CIMMYT efforts in this area are expected to expand. Currently, acceptable gluten strength levels are available in CIMMYT germplasm. However, more efforts are needed to enhance the level of yellow pigment concentration in CIMMYT-derived germplasm.

Current and Future Challenges

Marginal and nontraditional areas

With increasing demand for food from traditional wheat growing areas, agricultural production is extending to marginal areas. In nontraditional areas, tremendous efforts are under way to grow wheat

Table 10.9. Quality data for DQN lines and known varieties, Y92-93.

	SDS Sedim. (ml)	Pigment (ppm).
DQN lines		
Green 38	16.0	9.6
Serra	16.0	10.7
Phaethon	16.5	10.2
Solga 8	16.5	10.8
Croc_1	16.0	12.3
Arlin	17.0	11.0
Varieties		
Mexi75 = Stork'S'	14.0	8.6
Yav79 = Bittern'S'	12.5	7.5
Altar84	14.0	7.8
Aconchi89	15.0	8.4
DON87	14.0	10.8
Waha	7.0	8.6
Belikh 2	13.5	5.0
Lahn	13.0	6.5
Omrabi 5	11.0	9.6
Korifla	13.0	7.2

SDS Sedim. = Gluten quality parameter.

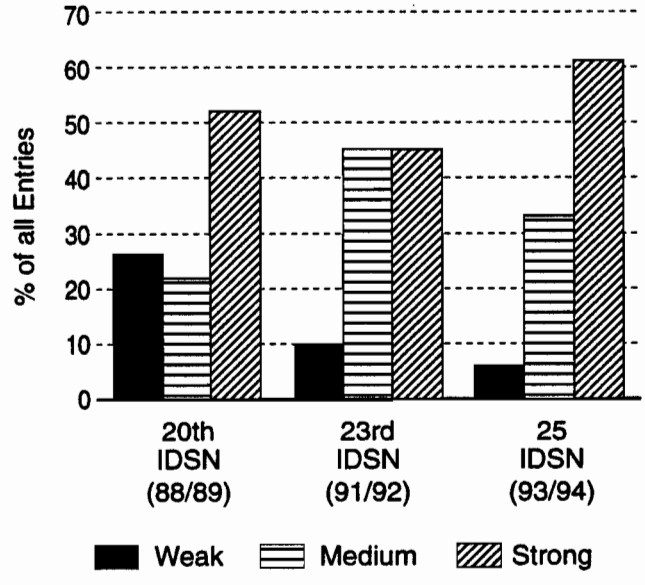


Figure 10.5. Quality improvement in CIMMYT germplasm (gluten strength in IDSN).

to meet local demands. Many constraints, mainly biotic and abiotic stresses, limit DW production in marginal and nontraditional areas. Genetic variability for resistance or tolerance to the stresses encountered in these environments is needed. Sources for this variability include interspecific and/or intergeneric donors. Thus, in the future, techniques of alien transfer and utilization of new biotechnological approaches as a tool to traditional breeding are expected to expand.

References

Abdalla, O., J.A. Dieseth, and R.P. Singh. 1992. Breeding durum wheat at CIMMYT. In pages 1-13, S. Rajaram, E.E. Saari, and G.P. Hettel, eds., Durum Wheats: Challenges and Opportunities. CIMMYT Wheat Special Report No. 9.

Byerlee, D. 1992. Impact of durum wheat breeding in developing Countries: A dilemma for the future. In pages 28-43, S. Rajaram, E.E. Saari, and G.P. Hettel, eds., Durum Wheats: Challenges and Opportunities. CIMMYT Wheat Special Report No. 9.

Cantrell, R.G. 1987. Breeding and genetics of durum wheat. Plant Breeding Review 5:11-32.

CIMMYT. 1991. 1990-1991. CIMMYT World Wheat Facts and Trends: Wheat and Barley Production in Rainfed Marginal Environments of the Developing World.

CIMMYT. 1992. Results of the 1988-89 Durum wheat nurseries. CIMMYT.

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

Payne, I.P., E.A. Jackson, and L.M. Holt. 1984. The association between gliadin 45 and gluten strength in durum wheat varieties: a direct causal effect or the result of genetic linkage? J. Cereal Sci. 2:73-81.

Rajaram, S., and R.A. Fischer. 1989. Wheat mega-environments. In pages 1-5, S. Rajaram and G.P. Hettel, eds., Wheat Breeders' Conference, Cd. Obregón, Son. 3-5 May, 1989.

Singh, R.P., E. Bechere, and O. Abdalla. 1992. Genetic analysis of resistance to stem rust in ten durum wheats. Phytopathology 82:919-922.

Singh, R.P., E. Bechere, and O. Abdalla. 1993. Genetic analysis of resistance to stem rust in nine durum wheats. Plant Dis. 77:460-463.

Waddington, S.R., M. Osmanzai, and J.K. Ransom. 1987. The yield of durum wheats released in Mexico between 1960 and 1984. J. Agric. Sci. 108:469-477.

Chapter 11.

Adaptation of CIMMYT's Durum Wheat Germplasm

J. Enrique Autrique

Introduction

The main goal of CIMMYT's durum wheat (DW) breeding is to assist developing countries in increasing DW productivity by supplying high yielding, widely adapted, disease resistant germplasm with good and end-use quality characteristics. To achieve its main goal, CIMMYT directs its durum breeding efforts towards the five mega-environments (MEs) listed in Table 10.1 in Chapter 10.

Multilocation testing through CIMMYT's International Nursery Network, to determine germplasm adaptation and to identify parental lines for crossing program, has led to the successes of the Wheat Program. Through its dynamic breeding program, CIMMYT has been able to provide developing countries with broadly adapted germplasm that performs exceptionally well in one or more ecological regions and performs well under both high and low-input conditions (CIMMYT 1985). Such basic germplasm has been utilized and released as varieties in many parts of the world (Byerlee 1992).

Clustering of Testing Locations

The usefulness of germplasm and information usually is dependent upon similarities in biotic and abiotic stresses that affect cultivar selection and performance within programs. Over the last 24 years, the Elite Durum Yield Trial (EDYT) has been sent to cooperators around the world. This trial is a replicated nursery that is formed by using the germplasm adaptation data from the International Durum Screening Nursery (IDSN). Clustering of locations on a yearly basis groups the testing sites according to the degree of stress, basically stress-free locations and locations with various degrees of stress (CIMMYT 1992, 1995). Further analysis on six years of data provided by the cooperators was used to group the testing sites. The only variable used to detect similarities between locations was yield. Thirty-two locations of the more than 40 reported each year had data available for the six years. Cluster analysis shows three different groups, namely Groups A, B, and C (Figure 11.1).

Group A includes 12 locations with relative shorter flowering times, but longer grain-filling periods. It includes locations with northern and southern latitudes ranging from 20 to 38°. It is composed of irrigated locations or sites with high precipitation. The mean yields for these locations are intermediate as compared to the B (highest) and the C groups (lowest). The second group (B) includes 10 locations with longer growing cycles, high precipitation, and generally located between 38-48°N of latitude except for two locations (South Africa, lat. 32°S; Chile 33°S). All these locations are high-rainfall environments (ME2), with the exception of La Platina, Chile, which is irrigated (ME1). The third group (C) includes 10 locations with intermediate days to heading and shorter grain-filling periods. The latitude is generally between 30-40°N, except for two locations Arusha, Tanzania (4°30'S) and Cochabamba, Bolivia (17°30'S), and precipitation ranges from low (215 mm) to high (688 mm). Compared to the six-year grouping, individual year-site clustering might be affected by the seasonal weather variations observed. Relationships among test sites of 17 years of international winter wheat nurseries were largely associated with yield, heading and ripening dates, grain-fill duration, and winter survival (Peterson and Pfeiffer 1989).

Specific and Wide Adaptation

Mean yield of the top five experimental lines was calculated and compared to the local check as a way to determine specific adaptation of the EDYT genotypes, since the local check represents specific adaptation of the test site. Data received by CIMMYT from more than 45 cooperators each year (282 locations for the

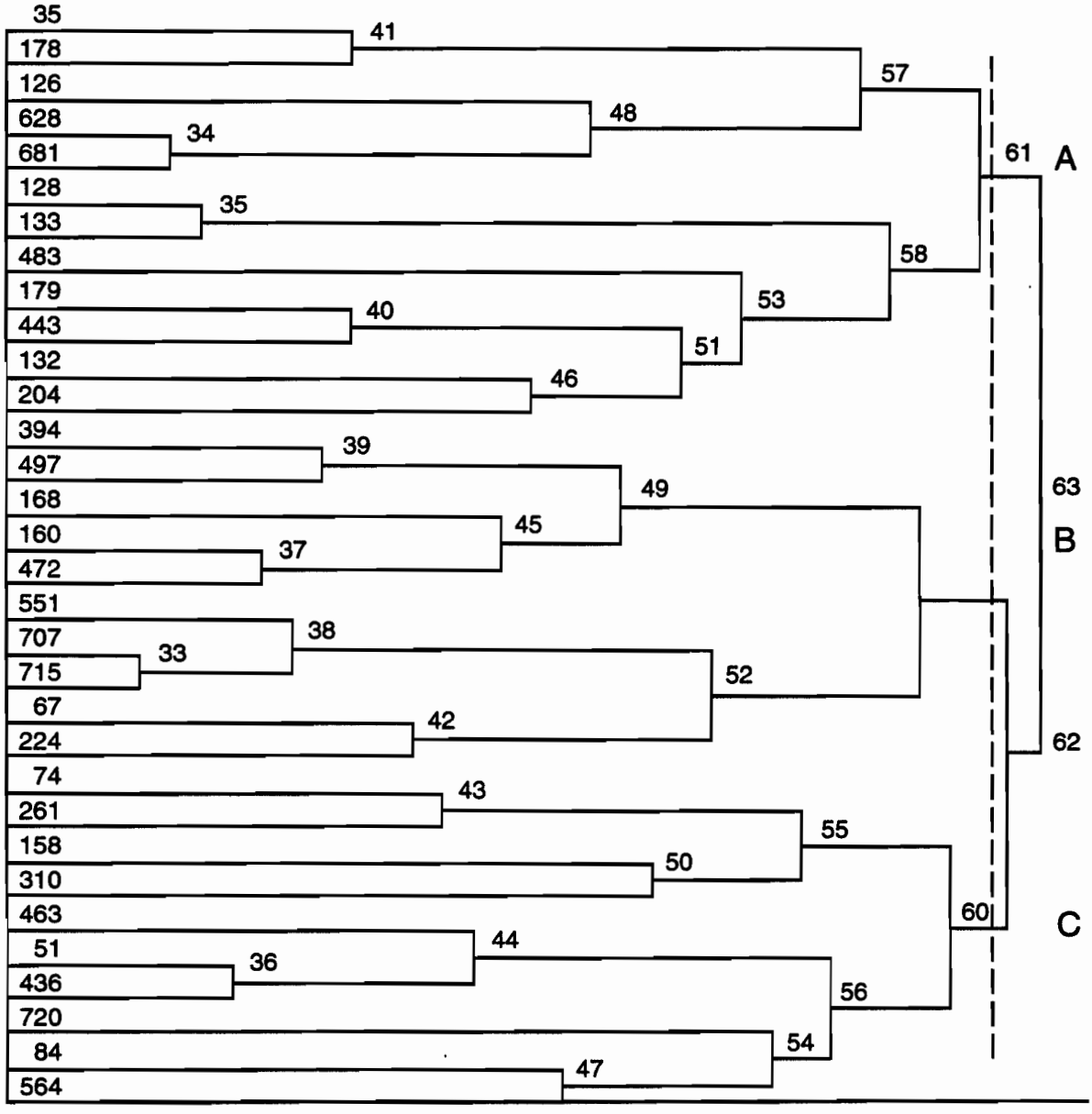


Figure 11.1. Clustering of locations based on six years of data from the Elite Durum Yield Trial (EDYT). Location codes correspond to the following sites: 35 Beja, Tunisia; 178 Sohag, Egypt; 126, 628 La Dulce and Buck, Argentina; 681 Rancagua Graneros, Chile; 128 El Batan, Mexico; 133 Sonora Dryland, Mexico; 483 Tel Hadya, Syria; 179 Beni-Suef, Egypt; 443 Iari-Delhi, India; 132 Sonora Irrigated, Mexico; 204 Indore, India; 394 Hohenheim, Germany; 497 Lincoln, New Zealand; 168 La Platina Santiago, Chile; 707 Macerata, Italy; 715 Yvelines, France; 67 Gross Enzerszorf, Austria; 224 Chirpan, Bulgaria; 74 Thessaloniki, Greece; 261 Diyarbakir, Turkey; 158 Cochabamba San Benito, Bolivia; 310 Jerez, Spain; 463 Islamabad, Pakistan; 51 Ludhiana, India; 436 Cordoba El Envinar, Spain; 720 Arusha, Tanzania; 84 Elvas, Portugal; 564 Faisalabad, Pakistan.

six years) show that the mean performance of the top five yielding lines were superior to the local checks in 78% of the locations. Table 11.1 summarizes the six years of data based on the mean yield of locations and locations showing better performance of the experimental lines over the local check. From the 15th to the 20th EDYT, an increase of the proportion of the mean of the top yielding genotypes above the local checks is observed (Figure 11.2). Some of the local checks that had higher yields are CIMMYT-derived varieties released in some of those countries.

Six years of EDYT data from the different test sites show about 60% of the locations with yields lower than 5 t/ha. Under these environments, the top five yielding lines were superior to the local check in 73% of the test sites. In some of the sites where local checks were superior, the highest yielding

Table 11.1. Location showing superior performance of the top 5 yielding experimental lines compared to the local check across 6 years of data of the EDYT according to location mean, and the countries in which the local check was superior to the top 5 lines.

Yield range kg/ha	Num. of locations	Locations with Mean Top 5 > Local Check		Countries*
		Num.	%	
< 2500	62	46	74	Ecuador (2), Algeria, India (2), Bolivia, Canada, Syria (2), Bulgaria, Ethiopia, Sudan, Thailand, Cyprus, Peru
2500-5000	108	79	73	India (7), Ecuador, Costa Rica, Italy (2), Pakistan (5), Greece (2), Peru, Spain, Austria (2), Turkey, Argentina, Bulgaria, Tunisia Chile, Kenya, Korea
5000-7500	73	59	81	Kenya, France (2), New Zealand (2), India, Germany (3), Austria, Chile, Spain, Pakistan
> 7500	37	32	87	Chile (2), Hungary (2), South Africa

* Number in parenthesis indicates the number of locations in that country within a year and/or the number of years.

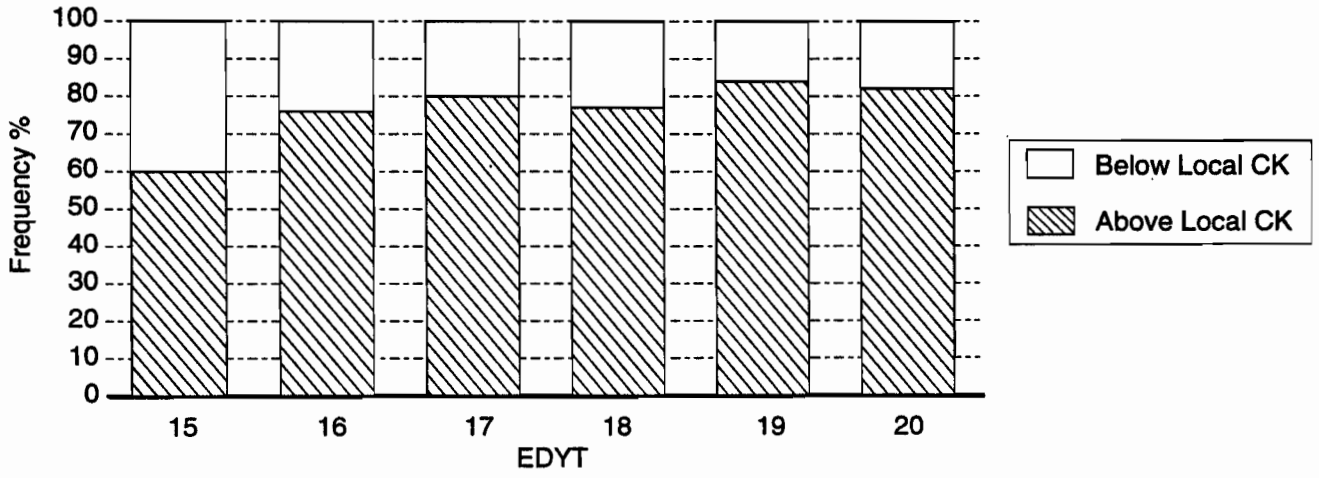


Figure 11.2. Proportion of testing sites in which the mean of the top five yielding DW lines was above or below the performance of the local check over six years of EDYT data.

experimental line was equal or superior to the local check (Figures 11.3 and 11.4). Biotic and abiotic stresses had an impact in the lower performance of the highest yielding durum lines in specific locations. Some of these factors include low tolerance to acid soils (Ecuador), leaf and stem rust resistance (Ethiopia, Kenya), heat (Sudan, India, Costa Rica, Thailand), and high latitude and powdery mildew (Europe, New Zealand). Stem rust resistance in Ethiopia has been improved through the use of locally adapted germplasm, but further work is needed to select for early or late genotypes as phenology seems to be important in clustering of sites, and increase the levels of powdery mildew resistance. Selection of advanced lines under high temperatures is a selection methodology undertaken a few years ago.

A combination of high yield potential and wide adaptation is a common feature of CIMMYT DW advanced lines. Mexicali (Stork), and Yavaros (Bittern) are good examples of this combination of attributes for a given line since they were released in 9 and 10 different countries, respectively

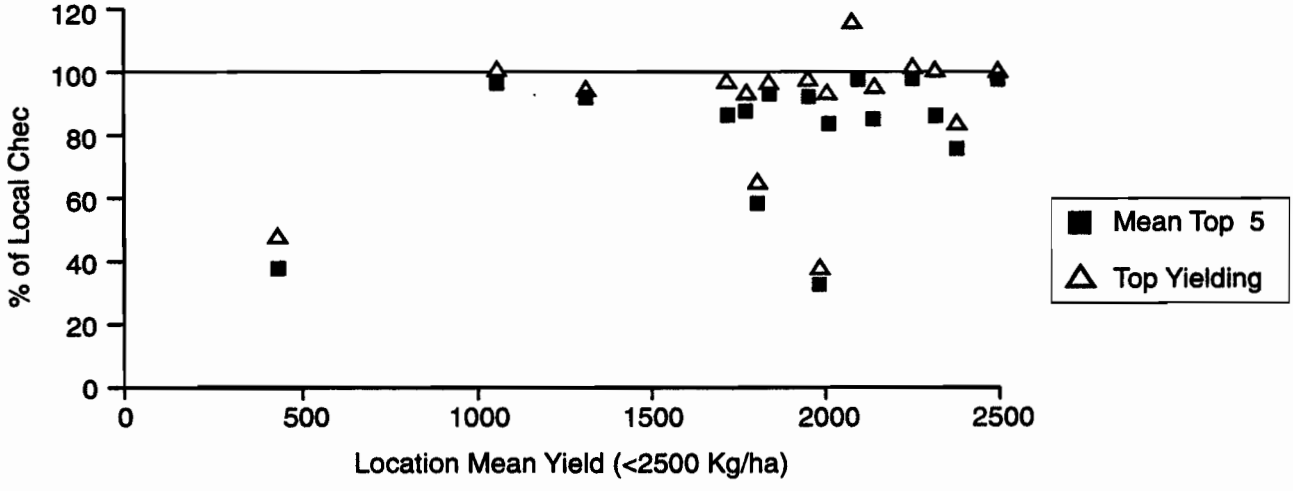


Figure 11.3. Mean of the top five yielding lines and the top yielding genotype as a percent of the local check in locations, based on location mean of <2500 kg/ha, where the local check was superior.

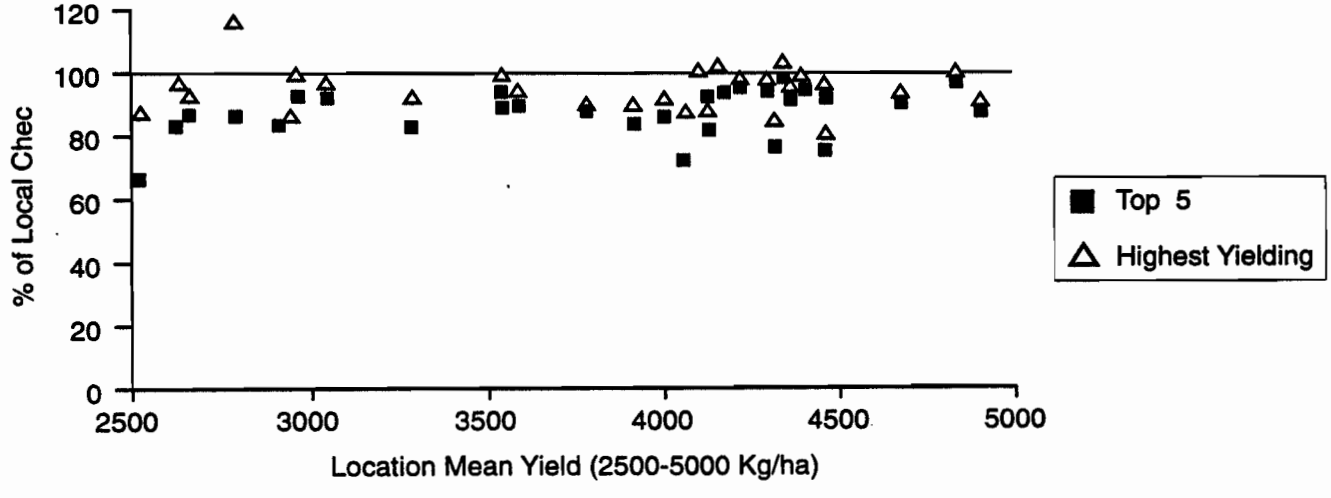


Figure 11.4. Mean of the top five yielding lines and the top yielding genotype as a percent of the local check in locations, based on location mean of 2500-5000 kg/ha, where the local check was superior.

(Byerlee 1992). The mean of the top five yielding lines across all environments was superior to the mean of the DW checks (Figure 11.5). These checks include Yavaros 79, Mexicali 75, and Altar 84. With the six years of EDYT data used (Brajcich et al. 1988, 1989; Abdalla et al. 1990; CIMMYT 1992, 1993, 1995), high yielding, stable lines have been identified by the method of Westcott (1987) and by the stratified ranking technique (Fox et al. 1990), which provides a rapid assessment of broad adaptation.

Comparative Yield Trial

Different selection strategies have been proposed for detecting lines with tolerance to stress environments. Based on theoretical considerations, Rosielle and Hamblin (1981) suggested that, for a yield increase to occur in a nonstress environment, the genetic variance in a stress environment must be greater than that in a nonstress environment. Contrary to this point, it was proposed that selection under stress conditions is expected to be more efficient than selection under favorable environments when dry areas become the target environment (Ceccarelli et al. 1987, Nachit 1992). It has been stated that optimum environments are better for selection when a target environment's average yield is about 3.0 t/ha. On the other hand, in environments under 1.0 t/ha conditions, materials selected under favorable environments are not expected to perform better than local cultivars (Acevedo and Ceccarelli 1989). Despite the difficulties of breeding for semiarid conditions, notable progress has been made by selecting genotypes under reduced irrigation at Obregón. The line source irrigation system (Hanks et al. 1976) was also used to identify material with yield stability under various moisture stress conditions (Abdalla et al. 1992).

High-yielding advanced lines, selected from a full irrigation yield trial and high yielding lines selected under reduced irrigation, were compared under four different environments (full irrigation, two irrigations, one irrigation, and heat). Results from two years of evaluation showed significant differences for the group of lines selected from full irrigation (ME1) compared to the ones selected under reduced irrigation (ME4) (Figure 11.6) except for a single environment with one irrigation.

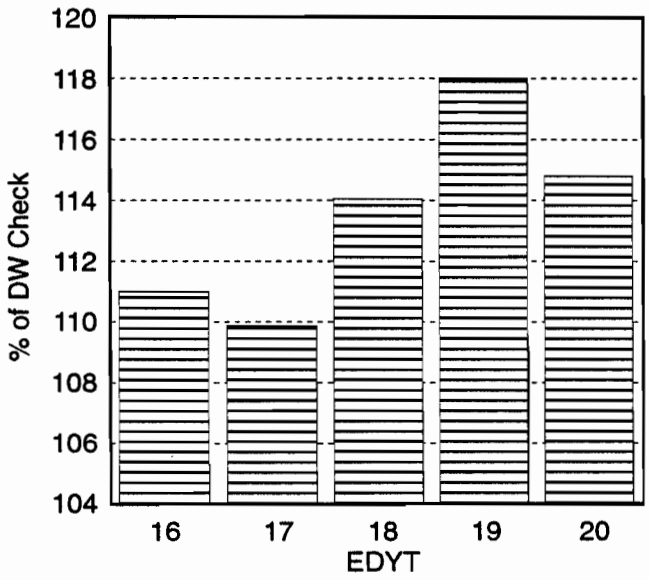


Figure 11.5. Mean of the top five yielding lines compared to the mean of the durum wheat checks included in the EDYT.

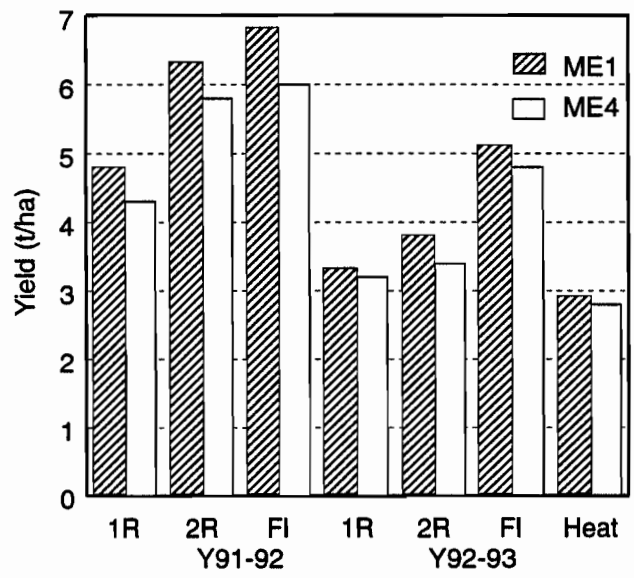


Figure 11.6. Mean yield for ME1 and ME4 lines tested under different environments (1R: one irrigation, 2R: two irrigations, FI: full irrigation).

Within the top 10 lines of each test environment, a larger proportion of ME1 lines was found compared to ME4 lines (7 out of 10). Based on AMMI analysis using IPCA1 values, the lines selected from ME1 environments showed a lower GxE interaction compared to the ME4 lines. Lines selected under full irrigation had a greater number of spikes/m^2, grains/m^2, higher biomass, flowered later, and were shorter than the lines selected under reduced irrigation (Table 11.2).

Based on the genotypes used in this study, lines selected under high-input environments performed better than the set of lines selected under low irrigation, and ME1 lines showed better yield stability across the environments tested. This set of lines was distributed in the 23rd EDYT for worldwide evaluation.

Table 11.2. Comparison of means over environments between ME1 and ME4 lines for some of the traits measured.

Trait	ME1	ME4
Grains/spike	41	42
Spikes/m2	321	266 *
Grains/m2	12861	11712 *
Biomass (t/ha)	14.54	13.94 *
Days to Heading	73	70 *
Days to Maturity	120	119
Plant Height (cm)	75	80 *

* Significantly different at the 0.05 probability level

Conclusions

Over the last 25 years, CIMMYT has been supplying NARSs with germplasm having specific and wide adaptation, yield stability, and improved quality characteristics. The success of the breeding methodology can be measured by the number of varieties that have been released in many countries. CIMMYT's principal test site, Ciudad Obregón, Sonora, was selected as the most suitable for screening, based on the correlation of between-mean grain yield of genotypes at each location and the mean yield across locations, based on 19 years of international data (Braun et al. 1992). More efforts are underway to improve some specific adaptation traits needed for some of the targeted environments.

References

Abdalla, O., T. Payne, P. Fox, and F. Cardenas. 1990. Results of the 17th Elite Durum Yield Trial (EDYT), 1987-88. Mexico, D.F.: CIMMYT.

Abdalla, O., J.A. Dieseth, and R.P. Singh. 1992. Breeding durum wheat at CIMMYT. In pages 1-13, S. Rajaram, E.E. Saari, and G.P. Hettel, eds., Durum Wheats: Challenges and Opportunities. Wheat Special Report No. 9. Mexico, D.F.: CIMMYT.

Acevedo, E., and S. Ceccarelli. 1989. Role of the physiologist-breeder in a breeding program for drought resistance conditions. In pages 117-139, F.W.G. Baker, ed., Drought Resistance in Cereals. CAB International.

Brajcich, P., M. Alcala, and M.T. Nieto-Taladriz. 1988. Results of the 15th Elite Durum Yield Trial (EDYT), 1985-86. Mexico, D.F.: CIMMYT.

Brajcich, P., M. Alcala, and M.T. Nieto-Taladriz. 1989. Results of the 16th Elite Durum Yield Trial (EDYT), 1986-87. Mexico, D.F.: CIMMYT.

Braun, H.J., W.H. Pfeiffer, and W.G. Pollmer. 1992. Environments for selecting widely adapted spring wheat. Crop Sci. 32:1420-1427.

Byerlee, D. 1992. Impact of durum wheat breeding in developing countries: A dilemma for the future. In pages 28-43, S. Rajaram, E.E. Saari, and G.P. Hettel, eds., Durum Wheats: Challenges and Opportunities. Wheat Special Report No. 9. Mexico, D.F.: CIMMYT.

Ceccarelli, S., M.M. Nachit, G.O. Ferrara, M.S. Mekni, M. Tahir, J. Van Leur, and J.P. Srivastava. 1987. Breeding strategies for improving cereal yield and stability under drought. In pages 101-114, J.P. Srivastava, E. Porceddu, E. Acevedo, and S. Varma, eds., Drought Tolerance in Winter Cereals. John Wiley & Sons Ltd.

CIMMYT. 1985. CIMMYT Research Highlights 1984. Mexico, D.F.

CIMMYT. 1992. Results of the 1988-89 Durum wheat nurseries. Mexico, D.F.: CIMMYT.

CIMMYT. 1993. Results of the 19th Elite Durum Yield Trial (EDYT), 1989-90 . Mexico, D.F.: CIMMYT.

CIMMYT. 1995. Results of the 20th Elite Durum Yield Trial (EDYT), 1990-91 . Mexico, D.F.: CIMMYT (in preparation).

Fox, P.N., B. Skovmand, B.K. Thompson, H.J. Braun, and R. Cormier. 1990. Yield and adaptation of hexaploid spring triticale. Euphytica 47:57-64.

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

Nachit, M.M. 1992. Durum breeding for Mediterranean drylands of North Africa and West Asia. In pages 14-27, S. Rajaram, E.E. Saari, and G.P. Hettel, eds., Durum Wheats: Challenges and Opportunities. Wheat Special Report No. 9. Mexico, D.F.: CIMMYT.

Peterson, C.J., and W.H. Pfeiffer. 1989. International winter wheat evaluation: Relationships among test sites based on cultivar performance. Crop Sci. 29:276-282.

Rosielle, A.A., and J. Hamblin. 1981. Theoretical aspects of selection for yield in stress and non-stress environments. Crop Sci. 81:943-946.

Westcott, B. 1987. Method of assessing the yield stability of crop genotypes. J. Agric. Sci. 108:267-274.

Chapter 12.

Durum Wheat Breeding in the Mediterranean Dryland Region

Miloudi M. Nachit

Durum wheat (*Triticum turgidum* L. var. *durum*) covers 10% of the total wheat area in the world. About 50% of this area in the world is in the developing countries, and 80% of this area is found in the Mediterranean region of West Asia and North Africa (WANA) region. Most dishes and food products in the WANA region include durum grain used in the production of local breads, burghul, frike, couscous, and pasta. The consumption of durum grain is very high and ranges from 150 to 200 kg/person per year; durum consumption is the highest in the rural areas.

In the WANA region, durum is grown in areas where drought may occur alone or in combination with each of the extreme thermal stresses at various stages of crop development. Further, even when the crop is grown in an "optimum moisture environment", occasional periods of stress due to lack of moisture or to temperature extremes may occur during the growing season. Use of irrigation in this region is limited and in many areas nonexistent. Therefore, the genetic manipulation of plants to improve the productivity and stability of durum wheat through improvement to abiotic stress resistance continues to be the only possible and practical solution. In addition to these stresses, durum wheat yields in the WANA region are reduced by biotic stresses and poor crop management and weed control.

Four major agro-ecological zones have been determined in terms of prevailing abiotic and biotic stresses with the aim to develop specific germplasm with the required genes of resistance for the environmental constraints in each agro-ecological zone.

- Low rainfall (below 350 mm) and low winter temperatures: this zone covers approximately 40% (3.5 million hectares) of the total area sown with DW in the WANA region. The major abiotic production constraints are drought, cold, and terminal stress (drought and heat); and biotic stresses: yellow rust, common bunt, wheat stem sawfly, and sunni pest. This agro-ecological zone is represented by the continental and high altitude areas of Morocco, Algeria, Syria, Turkey, and Iraq.
- Low rainfall (below 350 mm) and mild winter temperature: this zone covers approximately 2.5 million hectares or 25% of the land cultivated with durums in the WANA region. It is mainly found in the coastal and southern latitude areas of North Africa. The major abiotic stresses in this zone are drought and terminal stress (heat and drought), and the biotic stresses are *Septoria tritici*, tan spot, leaf rust, Hessian fly, and dryland root rot.
- Moderate rainfall (350-600 mm) and low winter temperatures: this zone covers 1.5 million hectares or 17% of the total durum growing area in the region. It includes such areas as northern Morocco, northeastern Algeria and Syria, and the southwestern parts of Turkey. Spells of cold, frost, and sorocco frequently occur and affect durum yields. The biotic constraints in these areas are: yellow rust, *Septoria tritici*, tan spot, leaf rust, and sunni pest.

- Moderate rainfall (350-600 mm) and mild winter: around 1 million hectares are grown in this zone that are mainly found in North Africa and southwestern Turkey. In addition to climatic variation, diseases and insects are the major constraints. The area under full irrigation is small and confined to Egypt, Saudi Arabia, and to some parts of Syria and Iraq. However, full and supplementary irrigation schemes are increasing in most durum growing countries in WANA region.

As the DW growing environments in WANA region are mainly located in areas with alternating stressed and favorable conditions, the joint CIMMYT/ICARDA Durum Project at Aleppo, Syria, has developed a strategy that aims at breeding improved germplasm with resistance to abiotic and biotic stresses and with responsiveness to improved conditions. This strategy also uses the introgression of desirable genes from landraces and wild relatives to cultivated durums and employs the selection and testing in contrasting and representative environments of Mediterranean drylands. Mediterranean DW landraces possess desirable traits that are lacking in improved materials, such as resistance to drought and cold, early growth vigor, long peduncle, and fertile tillering ability under stress conditions. In addition to landraces, wheat relatives, e.g., *Triticum dicoccoides, Triticum monococcum, Aegilops* spp., etc.) provide valuable sources to improve disease resistance and grain quality.

In our selection approach, all early segregating populations are subjected to the stresses in contrasting and representative environments with the aim of identifying the populations that do particularly well in certain environments and are not sensitive to the stresses of other environments. The bulk method is used to select populations across environments; and the pedigree method to select individual plants from the populations that were selected over several environments. Earliness, fertile tillering, spike fertility, peduncle length, and early plant vigor are associated with higher grain yield under dryland conditions.

Although the delimitation of agro-ecological zones in the WANA region decreases the GxE interaction, it does not necessarily eliminate it because the year-to-year and site-to-site variations within a zone can still be very important and make it imperative to look for cultivars possessing an acceptable degree of consistency of superior performance (commonly called stability) across a series of environments. The durum multilocation testing program provides data for assessing consistency of relative genotype's performance. Genetic stocks have been developed with combined resistances to abiotic stresses and high yield.

The selection for biotic stress resistance exploits indigenous races of pathogens to create artificial inoculation. Multilocation resistance screening and testing in "hot spots" is also made to detect other races of diseases. Improved resistance was achieved for yellow rust, stem rust, leaf rust, *S. tritici*, common bunt, and BYDV. The resistance genes for the different diseases are incorporated into drought, cold, and heat-tolerant durum genotypes. Further, most of the advanced lines of DW exhibit medium to high resistance to the wheat stem sawfly under natural infestation. Resistance to the wheat stem sawfly is apparently not restricted to stem solidness. However, several DW landraces from Morocco were found to possess solid stems and are now used in the crossing program for wheat stem sawfly resistance. Incorporation of resistance to the wheat stem sawfly from different sources and with different resistance mechanisms are combined to develop stable resistance. Screening and breeding for resistance to Hessian fly and aphids are carried out jointly with the national programs of Morocco and Egypt. Most of the advanced genotypes included in the regional nurseries and trials are combining biotic with abiotic resistances.

The WANA region has a large variety of foods made from durum grain. The most used quality test parameters are protein content (%), virtuousness, sedimentation test (SDS), carotene content, grain size, and the g gliandin 45 band. Crosses are made to increase industrial and nutritional qualities of the stress tolerant germplasm. WANA landraces are the best sources for local end products, while the *T. dicoccoides* are used to increase grain protein content and virtuousness.

Our research work has shown that selection efficiency is greatest when selection is made in testing sites that are environmentally similar to the target environment(s) where the cultivar will be commercially grown; and that resistance to abiotic stresses can be combined with yield potential. Several lines from the joint CIMMYT/ICARDA durum nurseries have been released in different countries: Waha (Turkey, Syria, Cyprus, Jordan, Lebanon, Algeria, Saudi Arabia, Portugal), Korifla (Syria, Algeria, and Jordan), Belikh2 (Lebanon), Omrabi (Syria, Jordan, Morocco, Tunisia, Algeria), Sebou (Morocco, Lebanon, Saudi Arabia), Kabir (Algeria), Brachoua (Libya), Marjawi (Libya), and Lahn (Syria). Although the release of abiotic stress tolerant and high yielding durum varieties is recent, the impact of these varieties have already started to be manifested.

Chapter 13.

Triticale Breeding at CIMMYT

Wolfgang H. Pfeiffer

The Past

The major food crops were selected at least 3000 years ago. Triticale (Tcl), the first successful "manmade" cereal crop, was transformed from a botanical curiosity in 1876 to an accepted commercial crop in less than 100 years. In 1965 when the Tcl program was initiated, goals of the early CIMMYT scientists were to develop a grain crop that combined the quality attributes of wheat with rye's robustness, biotic/abiotic stress tolerance, and low-input requirements. These were formidable challenges, given the combination of problems Tcl initially possessed. Since then, progressive advances in overcoming Tcl's technical limitations have been made (Varughese et al. 1987). Today, Tcl is an accepted commercial crop in more than 30 countries and grown on about 2.5 million hectares worldwide. About 70% of the area is under winter (WTcl) and facultative (FTcl) types and 30% under spring types (STcl). CIMMYT is the major source of Tcl germplasm for many national programs and an ancestral constituent of nearly all commercial cultivars.

The Present

Modern Tcl improvement concentrates on two objectives: 1) to generate crop options and 2) to generate utilization options. Crop options are associated with crop adaptive patterns, economic comparative advantages, and issues of environmental sustainability. Utilization options refer to consumption, marketing, and end-uses. However, for Tcl, a crop with multiple end-uses, adaptation for grain Tcls and grazing Tcls will most likely differ. Since crop options and marketing options are linked, adaptation has to be defined in terms of utilization (Pfeiffer 1992b). The social sciences can assist in defining the niche of Tcl in agricultural systems (Carney 1990) to provide and concretize breeding goals and target zones. Capitalizing on crop and marketing options has caused a shift and expansion in Tcl breeding objectives over the last six years.

Adaptive Patterns

Focus on complete karyotype triticales for marginal environments

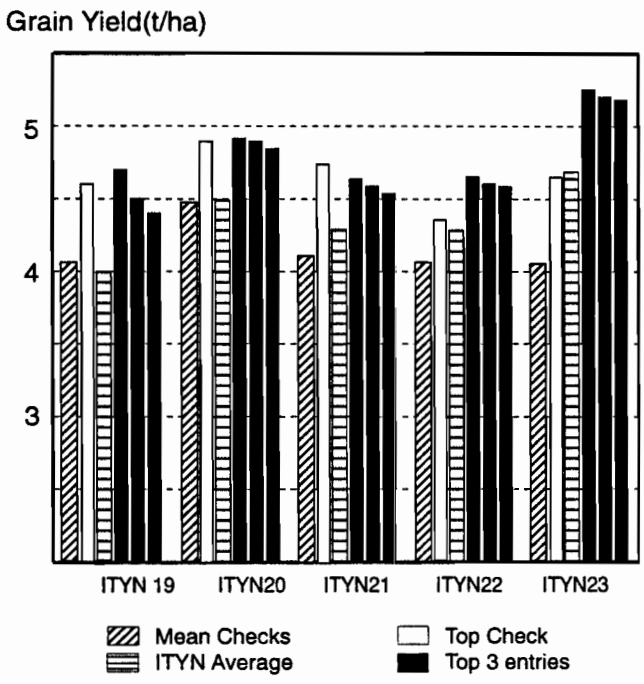
Regression techniques and multivariate analysis have been used to define areas of adaptation of complete and 2D(2R) substituted Tcls and compare Tcls with other cereals. Since the late 1980s, these methods are routinely used to define and delineate agroecological zones, or mega-environments, according to a number of classification goals to direct breeding strategies (Peterson and Pfeiffer 1989; Pfeiffer and Braun 1989; Fox et al. 1990; Crossa et al. 1990a,b; Pfeiffer et al. 1990; Pfeiffer and Fox 1991; Pfeiffer et al. 1991a; Braun et al. 1992; Pfeiffer et al. 1993). Different types of analyses with ITYN data and past experience indicate that Tcl has increasingly revealed its potential under marginal growing conditions. In ME2, ME3, ME4, and ME6, complete triticales show distinct yield superiority and appear to have adaptive advantages over 2D(2R) types, bread wheat (BW), and durum wheat (DW) due to better resistance to biotic and abiotic stress. In highly productive ME1 environments, the differences between complete and 2D(2R) types were

small and Tcl did not appear to have distinct adaptive advantages over wheat. These observations verified previous results and implied that the future of Tcl as a commercial crop lies with complete triticales in more marginal environments, while both karyotype Tcls could complement wheat production in ME1 and certain agro-ecological niches. These findings were prompted by a shift in Tcl breeding emphasis from 2D(2R) substituted to complete R genome types from the mid-1980s onwards (Varughese et al. 1987). The ratio of complete to substituted Tcls shifted gradually from 25:75 in 1985 to 95:5 by 1992.

Results

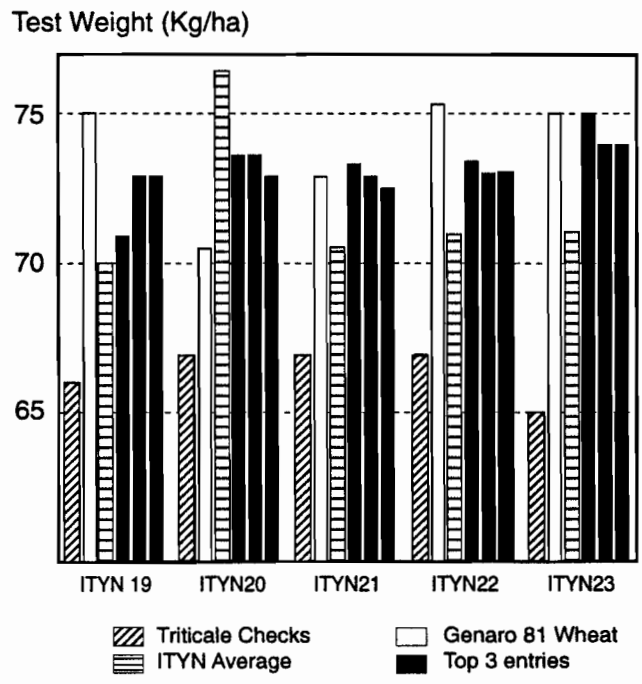
Grain yield across locations reflects the genotypic response to the total environment as a combined measure of all biotic and abiotic factors involved. Hence, the ITYN data presented in Figures 13.1 and 13.2 should be interpreted as overall progress achieved (Pfeiffer and Braun 1989, Pfeiffer and Fox 1991; Braun et al. 1992). Average grain yields, relative ranks, and test weights across ITYN sites and comparisons with long-term checks indicate high genetic gains for both traits, particularly in recent years. Results are verified by ITSN data where the same genotypes have been tested one year ahead (ITYN 23—preliminary results across 38 sites correspond to ITSN 22). During 1991-1993, approximately 35 CIMMYT Tcls were released by NARSs.

Chromosomal configurations—Results from recent ITYNs and 1990-1993 variety release data suggest adaptive advantages of complete triticales carrying a 6D(6A) substitution. The 6D(6A) substitution rapidly spread to about 50% of the CIMMYT advanced spring germplasm and probably through introgression of CIMMYT genotypes to winter germplasm. These observations suggest the exploitation of karyotypic variability as a promising strategy to increase yield potential and adaptation. A nearly complete series of D(A), D(B) and D(R) substitutions and/or translocations is now available (A.J. Lukaszewski, University of



Mean yield across sites, Checks: Can79, Alm83, Gen81, B-Wheat, Beagle, Eronga83

Figure 13.1. Triticale grain yield performance, 19th to 23rd ITYN.



Mean test weight across sites. Triticale checks: Can79, Alm83, Beagle, Eronga83

Figure 13.2. Triticale test weight performance, 19th to 23rd ITYN.

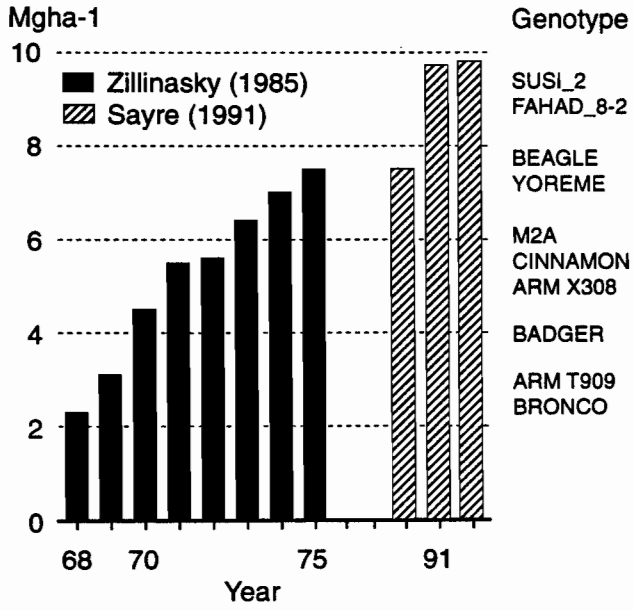
California, Riverside) and their influence in the background genome deserves study. Large-scale karyotyping in parallel to field testing will be required to determine the effects of interactions among chromosomal configurations. The optimal Tcl karyotype has to be determined and a single optimal chromosomal constitution for all situations is unlikely to emerge.

Definition of MEs and trait-oriented selection—In an effort to improve data quality and generate more suitable datasets across sites and years to describe and delineate MEs, the design of the ITYN has been changed (Pfeiffer 1992a). The number of ITYN entries increased gradually from 25 (ITYN 21) to 49 (ITYN 23), while the Randomized Complete Block (RCB) design was replaced by a 7x7 lattice design with 3 reps (ITYN 21) and 2 reps from ITYN 25 onwards. Once such MEs are precisely defined, in terms of genotype x environment interaction and utilizations, the underlying biotic and abiotic determinants will be identified in a future step. With stresses recognized, trait-oriented selection and breeding procedures could reinforce breeding triticales for both broad and specific adaptation and result in additional genetic gains (Pfeiffer and Fox 1991). Trait-based selection will facilitate the integration of newer biotechnology procedures.

Yield Potential

Hypothesis

At CIMMYT, breeding for yield per se is related to the different MEs and associated environmental yield potentials. Hence, breeding efforts have to take into account adaptive traits and yield stability, defined as spatial, temporal, and system-dependent yield fluctuations of adapted genotypes (Pfeiffer and Braun 1989; Pfeiffer and Fox 1991). Grain yield per se is the most important prerequisite of adaptation on the genotype level and hence is a priority objective. Further crop enhancement emphasizes the introgression of "protective gene-systems", primarily resistance to biotic and abiotic stresses and genetic system for industrial quality into high yielding genetic backgrounds. Incorporation or modification of such buffering mechanism increases realized environmental yield potentials and simultaneously yield stability and adaptation range. Increases in specific adaptation can increase wide adaptation and vice versa. Since yield per se is closely associated with input responsiveness, incorporation of input-efficiency at low production can shift cross-over points and enhance residual effects of high genetic yield potential (Pfeiffer 1989). This will be critical to ensure genetic gains and risk efficiency in highly variable environments, particularly in ME4 (Edmeades et al. 1988, Pfeiffer 1988, Pfeiffer et al. 1991b).



Cd. Obregón data

Figure 13.3. Triticale grain yield potential, 1968-91.

Results

Improvements in genetic yield potential in Tcl have been spectacular and are estimated at 2.5%/year (Figure 13.3). As Tcl grain yields over the last three years at ME1 Cd. Obregón equalled BW and Durum yields, record grain yields are reported in

recent ITYNs. Data from maximum yield potential trials suggest that increases in modern Tcls were due to a higher #grains/unit area via an increased number of heads/unit area. In 1990-91 to 1992-93 Cd. Obregón yield trials, approx. 17% of the entries yielded equal or higher compared with the checks.

Germplasm—Yield trial results from Cd. Obregón and population parameters for grain yield and associated agronomic traits suggest that high genetic gains for grain yield can be maintained; however, long-term genetic progress at past rates of > 2% is unrealistic. Compared with wheat, Tcl has higher biomass, 1000-grain weight (TGW), and no. of grains/head, while harvest index (HI) and no. of heads/unit area are lower and plants are, in general, taller. Grain yield is positively associated with TGW, number of grains/head, and plant height. Since the sterility problem has been largely solved, transformation of the higher biomass of Tcl via HI modification may allow relatively "easy" genetic gains. Further progress will evolve from exploiting the variability for yield components, such as TGW. High rates of progress in yield per se from germplasm developed from WTcl x STcl, Tcl x BW, 2D(2R) x complete Tcl crosses, and Tcls carrying chromosomal substitutions/translocations suggest future genetic gains from exploiting different gene pools.

Empirical approach—The empirical approach contributed significantly to past achievements via improvements in computerization, analytical procedures, data processing, machinery, and higher breeding efficiency manifested in larger numbers of field plots and extended multilocational testing. The Tcl project has been innovative in adopting these techniques: machine planting at all sites, the change from a 3-rep RCB (16 entries) to a 2-rep 8x8 lattice and spatial design, yield trials on beds, grouping of yield trial entries according to plant height and maturity, and computer-assisted design of crosses are examples of efforts to increase precision and efficiency (Pfeiffer et al. 1991b, Pfeiffer 1992a, Grondona et al. 1994). Future improvements in this areas can be expected.

Agonomic Traits

For most of the earlier problem traits, improvements have been significant and/or variability to guarantee future progress has been introgressed (e.g., plant height, head fertility, test weight, and days to heading/maturity). A wide range of different Tcls with novel plant architecture and compact, highly fertile head types with better threshability has been developed, while the frequency of closed canopy types increased with the spread of 6D(6A). The long grain-fill duration of Tcl when compared with wheat is one of the traits that warrant special attention in future breeding efforts. Long grain-fill duration provokes vulnerability in terminal stress and late/early frost situations with drastic effects on grain yield. Breeding for value-added traits is addressed by monitoring population parameters and capitalize on actual trait expression to maximize selection gains (Pfeiffer et al. 1991c, Pfeiffer 1993). Resource allocation and the development of special trait populations (STP) are guided by the evaluation of projected genetic gains.

Abiotic Stresses

Breeding for marginal lands such as acid, sandy, or alkaline soils, trace element deficiency (copper, manganese, zinc) or trace element toxicity (high boron), and the different types of moisture stress environments constitutes a major effort in Tcl improvement. At CIMMYT, breeding for acid soils, moisture stress, and enhanced tolerance to high and low temperatures is addressed by exploiting Mexican-type environments (e.g., Patzcuaro for acid soils, Huamantla for moisture stress, and La Paz for salt).

The generation of moisture and temperature stress (e.g., late planting and reduced irrigation at Cd. Obregón) with mulitlocational testing over stress gradients was used. This methodology, which identifies input/stress-efficient and responsive genotypes, and shuttle breeding (e.g., with Brazil) are complemented by lab screening methods. Novel screening procedures will be employed as they evolve.

Preharvest sprouting resistance

High levels of alpha-amylase in Tcl seed and correlated preharvest sprouting are persistent problems in ME2, ME3, and ME6. Results from basic research conducted at CIMMYT resulted in a breeding strategy for enhanced sprouting resistance. It involved a line source gradient in a multi-environment testing strategy to combine and evaluate mechanisms/components that contribute to sprouting resistance (Trethowan et al. 1991, 1993, 1994). For sprouting resistance, significant progress has been achieved and further improvements can be expected, although in small incremental steps. High genetic gains may result from the application of novel techniques with the use of molecular and biochemical markers. Further, a modification of rye chromosome 6R may drastically enhance resistance (Gale et al. 1990). The 6D(6R) substitution in Tcl is now available and the effect of the 6R alpha-amylase in preharvest sprouting will be quantified.

Biotic Stresses

With the expansion of Tcl area, most wheat and rye diseases and insect pests occur on Tcl with the potential to cause serious epidemics. Compared with wheat, Tcl appears to have superior resistance to the rusts, *Septoria* spp., smuts, bunts, powdery mildew, take-all, eyespot, common root rot, cereal cyst nematode, Hessian fly, Russian wheat aphid (*Diuraphis noxia*), and virus diseases (BYDV, wheat streak, barley stripe mosaic, brome grass mosaic viruses). Greater susceptibility of Tcl to diseases caused by *Fusarium* spp., *Helminthosporium* spp., and bacterial diseases constitutes priorities in resistance breeding. *Puccinia* spp. (the rusts) require special attention due to their global importance and the evolution of virulent races of stem rust in Australia and Madagascar and stripe rust in the East African and Andean highlands. *Septoria nodorum* and BYDV also merit attention. In general, disease resistance in Tcl is based on major and partial gene resistance.

Breeding to incorporate and stabilize resistance, e.g., for the rusts, involves transfer of genetic systems for durable resistance (e.g., *Lr34*, *Sr2* complex from BW), major effective genes (e.g., *Lr19* from BW), and the identification and introgression of new sources of resistance (e.g., stripe rust resistance from *Triticum dicoccoides* derived from BW and DW). Shuttle breeding, the development of STPs, and targeting crosses based on information provided by cooperators are standard breeding procedures. Artificial inoculations and the consequent utilization of disease "hot spots" within and outside Mexico in germplasm development and screening are instruments to produce a continual flow of resistant germplasm in an effort to keep ahead of evolving pathogens.

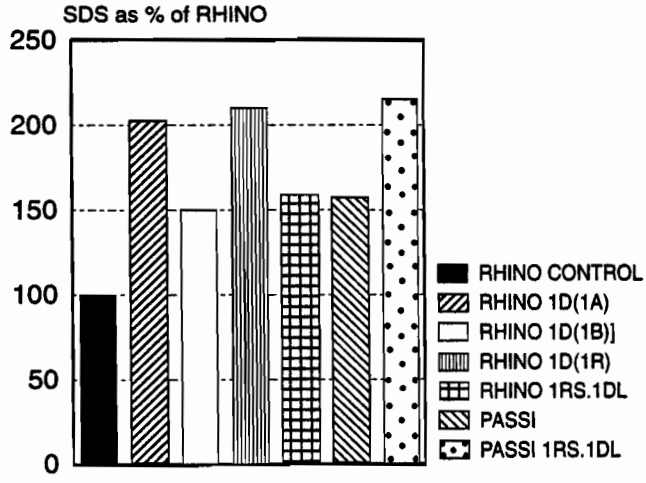
Genetic studies are warranted because disease reactions of triticale vary from combined resistance of the parents (i.e., wheat and rye), to resistance of only one of the parents, to resistance that is intermediate or inferior to both parents. The genes involved and their mode of action are largely unknown. A series of primary Tcls, suitable for genetic studies (CIMMYT hallmark BWs/DWs and German rye inbreds) has been produced in collaboration with scientists from Hohenheim University, Germany, and is currently being multiplied.

Utilization Options

The shift in breeding emphasis from 2D(2R) to complete R genome and 6D(6A) types in the 1980s was accompanied by improved test weights, but negative effects on baking quality (Pfeiffer 1992b). Research with wheat/Tcl grain and flour blends on milling and baking properties suggested blends for commercial use. Specialized requirements and markets for products for human consumption, high protein or high energy feed grain, and growing interest in forage and dual-purpose triticales were prompted in 1990 by end-use oriented and expanded breeding objectives. Further, projected genetic gains for quality traits, based on existing genetic variability and heritability estimates, and phenotypic correlations among these traits, suggested that breeding should be targeted to human and animal consumption (Table 13.1). Results indicate that, in general, genetic variability rather than heritabilities are limiting genetic progress and suggest that the development of special trait populations for such traits (e.g., protein concentration) is warranted (Pfeiffer et al. 1991c, Peña et al. 1992, Pfeiffer 1992b). Tcls with trait combinations required for specialist markets, such as malting, can be derived from the classes given in Table 13.1. By 1992, the whole range of products was available—complete karyotype triticales with loaf volumes between 750 and 800 cc, excellent cookie lab scores, and spaghetti scores similar to durums.

Table 13.1. Tcl breeding objectives for human and animal consumption.

Human Consumption	Animal Consumption
Baking quality (hard)	Feed grain Energy
Cookie quality (soft)	Protein
Semolina quality (vitreous)	Forage/grain Dual purpose
	Forage Grazing/cut forage



A. LUKASZEWSKI RHINO SUBSTITUTION SERIES HMW SUBUNIT 2+12 ON 1D, 5+10 ON 1RS.DL

Figure 13.4. Effect of D genome high-molecular weight glutenin subunits on SDS-sedimentation.

In 1989, a strategy evolved to improve baking quality in hexaploid Tcl by capitalizing on high-molecular weight glutenin subunits (HMW), particularly allelic variants at loci Glu-A1 and Glu-B1. Research focused on the identification of HMW via SDS-PAGE and their association with industrial quality in Tcl. Evaluation of the baking properties of Tcl, including octoploid primaries, revealed that the relative importance of the HMW loci Glu-A1, Glu-B1, and Glu-D1 approximated a ratio of 20:30:50. The effects of allelic variants were the same as in BW and the strong negative effects of 6D(6A) on baking quality (Pfeiffer 1992b). Consequently, favorable HMW loci on Glu-B1 such as 7+8 and 17+18 were transferred from BW to Tcl and are combined in targeted crosses.

Results revealed that exploiting the existing variability for baking quality will not solve inherent limitations in industrial quality. This is because Tcls not only lack the Glu-D1, but carry the major endosperm proteins Sec-1, Sec-2, and Sec-3 on the rye genome, which are responsible for the poor baking quality of Tcl flour. A new era in Tcl quality came in 1991 with the availability of Glu-D1 in 1D(1A) and 1RS.1DL in the Tcl Rhino substitution series developed by A.J. Lukaszewksi at the University of California at Riverside (Figure 13.4). Drastic increases in SDS sedimentation values in a poor quality genetic background (Rhino) and a good

quality genetic background (Passi, and data measured on F3s from Passi backcrosses) suggest a future breakthrough may be forthcoming. Since 1992, the 1D(1A)—which carries band 5+10—1D(1B), and 1D(1R) substitutions are available. Presently, Tcls with two, three, and four doses of Glu-D1 are being developed. Once Glu-D1 has been exploited, future research should be extended to gliadins and secalins.

Forage and forage/grain dual-purpose Tcls

The development of forage and forage/grain dual-purpose Tcls brings a new area of Tcl enhancement to CIMMYT. This demand-driven effort will complement crop and livestock enterprises in developing countries. The requirements, in terms of growth habit and trait combinations (e.g., reduced awns), are highly specific to the target environment and management. Resources are being allocated to develop a range of germplasm products using the STcl, FTcl, and WTcl gene pools, which are suitable for dual purpose and multiple forage situations. Evaluation of forage nutritional parameters and testing under livestock grazing pressure is being conducted by collaborating NARSs on an informal basis (e.g., University of Saltillo and University of La Paz in Mexico). These collaborative projects should be formalized to capitalize on outside CIMMYT expertise and facilities.

Early forage research (Cd. Obregón, 1989-90) concentrated on determining the forage potential of STcl/FTcl compared with oats and barley as alternate forage commodities in one-cut situations. Results suggested that existing STcls were suitable for early forage, hay, and whole crop silage (Pfeiffer 1992b). From 1990-91 onwards, a representative sample of the late STcl, FTcl, and WTcl gene pool was evaluated for forage potential in multiple forage harvests and grain-recovery potential (Pfeiffer 1992b). Guided by results and implications, a new international nursery (FWTcl) was assembled including advanced and segregating FTcl and WTcl grain and forage materials. From 1992 onwards, the FWTcl was distributed to 75 cooperators to open new utilization options for the farmers in our client countries. Parallel to the dissemination effort, traits such as reduced awns from different sources were identified, evaluated, and incorporated in the target gene pool. The first products of this effort, e.g., high yielding dual purpose Tcls with reduced awns and high grain protein concentration, are now available. During 1992 and 1993, seven CIMMYT Tcls have been released for forage utilization (S, F, and WTcls).

The Balance of Germplasm Diversity and Genetic Variability

Targeted crosses among adapted elite progenitors in tactical breeding activities ensure short-term progress, but there is a threat of genetic vulnerability, particularly in a manmade crop. Hence, strategic crop enhancement has to emphasize the generation and maintenance of genetic diversity, but carefully balance diversity objectives required to ensure long-term progress, with the relatively narrow genetic variability necessary to achieve short-term breeding goals (Pfeiffer et al. 1991c, Pfeiffer 1993). Trait-oriented expansion of the genetic base in Tcl and parent building are separated from tactical breeding activities and are addressed via the development of STPs. STP development facilitates the combination of traits from different unadapted sources with adapted sources, the use of different breeding methodologies, the evaluation and quantification of alternate gene sources, progress, and a close focus on objectives. In Tcl, the lack of evolutionary diversity may be overcompensated by a spectrum of possibilities to introduce variability.

Spring and winter wheat and rye gene pools are accessed through direct interspecific (BW x Tcl) and intraspecific (WTcl x STcl) crosses, and the production of octoploid (8x) and hexaploid (6x) primary Tcls followed by primary x secondary Tcl crosses. 8x/6x crosses guarantee an influx of cytoplasmic variability. Genetic systems from alien species e.g., *Triticum tauschii*, are transferred into Tcl via BWs carrying of alien introgressions, while complete x 2D(2R) Tcl crosses continue to be an important medium to introgress genetic variability—the two gene pools are distinct.

Advances in embryo rescue techniques, culture media, and particularly the use of callus culture and cloning with multiple plant regeneration have resulted in drastically increased success rates in primary production (Immonen and Pfeiffer 1991; Immonen et al. 1991, 1993). Further, cytologically more stable and hence "breeder friendly" primary Tcls have evolved from crosses with modern CIMMYT wheats. However, with a widening gap in agronomic performance between secondary and primary Tcls, the importance of primary production has decreased.

References

Braun, H.J., W.H. Pfeiffer, and W.G. Pollmer. 1992. Environments for selecting widely adapted spring wheat. Crop Sci. 32(6):1420-1427.

Carney, J. 1990. Triticale production in the Central Mexican Highlands: Smallholders' experiences and lessons for research. CIMMYT Economics Paper No. 2. Mexico, D.F: CIMMYT.

Crossa, J., P.N. Fox, W.H. Pfeiffer, S. Rajaram, and H.G. Gauch, Jr. 1990a. AMMI adjustment for statistical analysis of an international wheat yield. Theor. Appl. Genet. 80:27-37.

Crossa, J., W.H. Pfeiffer, P.N. Fox, and S. Rajaram. 1990b. Multivariate analysis for classifying sites: application to an international wheat yield trial. In pages 214-233, Proceedings Symposium Genotype-by-Environment Interaction and Plant Breeding, Baton Rouge, U.S.A., 11-15 Feb. 1990.

Edmeades, G.O., J. Bolaños, H.R. Lafitte, S. Rajaram, W.H. Pfeiffer, and R.A. Fischer. 1988. Traditional Approaches to Breeding for Drought Resistance in Cereals. In pages 27-52, W.G. Baker, ed., Drought Resistance in Cereals. ICSU, Paris.

Fox, P.N., B. Skovmand, B.K. Thompson, H.J. Braun, and R. Cormier. 1990. Yield and adaptation of hexaploid spring triticale. Euphytica 47:57-64.

Gale, M.D., J.E. Flintham, and D.J. Mares. 1990. Application of molecular and biochemical markers in breeding for low a-amylase wheats. In pages 167-175, K. Ringlund, E. Mosleth, and D.J. Mares, eds., Proc. 5th Int. Symp. on Preharvest Sprouting in Cereals. Norway.

Grondona, M.O., J. Crossa, P.N. Fox, and W.H. Pfeiffer. 1994. Analysis of variety yield trials using two-dimensional separable ARIMA processes. Biometrics (in press).

Immonen, A.S.T., and W.H. Pfeiffer. 1991. Callus culture in production of primary triticales: comparison of media and hormones. Agronomy Abstracts, p. 196.

Immonen, A.S.T., W.H. Pfeiffer, and R.M. Trethowan. 1991. 4x and 6x wheat and rye progenitors in triticale primary production. In pages 383-386, Proceedings 2nd International Triticale Symposium, Passo Fundo, Brazil, 1-5 Oct. 1990.

Immonen, A.S.T., G. Varughese, W.H. Pfeiffer, and A. Mujeeb-Kazi. 1993. Crossability of tetraploid and hexaploid wheats with ryes in triticale primary production. Euphytica 65:203-210.

Peña, R.J., W.H. Pfeiffer, A. Amaya, and J. Zarco-Hernandez. 1992. High molecular weight glutenin subunit composition in relation to the breadmaking quality of spring triticale. In pages 436-439, Cereals International Conference Secretariat 1991.

Peterson, C.J., and W.H. Pfeiffer. 1989. International winter wheat evaluation: relationships among test sites based on cultivar performance. Crop Sci. 29:276-282.

Pfeiffer, W.H. 1988. Drought tolerance in bread wheat—analysis of yield improvement over the years in CIMMYT germplasm. In pages 274-285, A.R. Klatt, ed., Wheat Production Constraints in Tropical Environments, Chiang Mai, Thailand, 19-23 Jan. CIMMYT/UNDP.

Pfeiffer, W.H. 1989. Breeding for drought tolerance. In pages 12-41, S. Rajaram and G.P. Hettel, eds., CIMMYT Wheat Breeders' Conference; Cd. Obregón, Son., Mexico, D.F.: CIMMYT.

Pfeiffer, W.H. 1992a. Analysis of international nursery data—Results and implications for international nursery design. In pages 23-28, P.N. Fox and G.P. Hettel, eds., Management and Use of International Trial Data for Improving Breeding Efficiency. Wheat Special Report No. 8. Mexico, D.F.: CIMMYT.

Pfeiffer, W.H. 1992b. Triticale improvement strategies at CIMMYT: exploiting adaptive patterns and end-use orientation. In pages 73-85, Proceedings, 7th Regional Wheat Workshop for Eastern, Central and Southern Africa, Nakuru, Kenya, 1991.

Pfeiffer, W.H. 1993. Triticale improvement strategies at CIMMYT: existing genetic variability and its implication to projected genetic advance. In Proceedings 5th Portuguese Triticale Conference. Elvas, Portugal, 22-24 May, 1990 (in press).

Pfeiffer, W.H., and H.J. Braun. 1989. Yield Stability in Bread Wheat. In pages 240-267, J.R. Anderson and B.R. Hazell, ed., Variability in Grain Yields: Implications for Agricultural Research and Policy in Developing Countries. The John Hopkins University Press, Baltimore and London.

Pfeiffer, W.H., and P.N. Fox. 1991. Adaptation of triticale. In pages 54-59, Proceedings, 2nd International Triticale Symposium, Passo Fundo, Rio Grande do Sul, Brazil, 1-5 Oct. 1990.

Pfeiffer, W.H., R.M. Trethowan, P.N. Fox, A. Amaya, J. Peña, F. Cardenas, and Rosa I. Magana. 1990. The nineteenth international triticale yield nursery (ITYN). Results of the 1987-88 triticale nurseries. Mexico, D.F.: CIMMYT.

Pfeiffer, W.H., M. Alcalá, J. Crossa, E.H. Vega, and R.I. Magaña. 1991a. The Twentieth International Triticale Yield Nursery (ITYN). El 20o Ensayo Internacional de Rendimiento de Triticale. The Twentieth International Triticale Screening Nursery (ITSN) El 20o Vivero Internacional de Selección de Triticale. Mexico, D.F.: CIMMYT.

Pfeiffer, W.H., K.D. Sayre, and R.M. Trethowan. 1991b. An integrated strategy utilizing line source gradients to develop input responsive triticales adapted to moisture stress. In pages 116-120, Proceedings, 2nd International Triticale Symposium, Passo Fundo, Rio Grande do Sul, Brazil, 1-5 Oct. 1990.

Pfeiffer, W.H., R.M. Trethowan, A.S.T. Immonen, A. Amaya, and R.J. Peña. 1991c. Population parameters and their implications for applied breeding and projection of expected genetic advance in triticale. In pages 121-124, Proceedings, 2nd International Triticale Symposium, Passo Fundo, Rio Grande do Sul, Brazil, 1-5 Oct. 1990.

Pfeiffer, W.H., P.N. Fox, J. Corbett, Ma. T. Rodriguez, and R.I. Magaña. 1993. The twenty-first and twenty-second International Triticale Yield Nurseries (ITYN). El 21o y 22o Ensayos Internacionales de Rendimiento de Triticale. (ITYN). CIMMYT, Mexico, D.F.

Trethowan, R.M., R.J. Peña, W.H. Pfeiffer, and A. Amaya. 1991. Using line source gradients in a multi-environment testing strategy to combine and evaluate different mechanisms contributing to sprouting resistance. In pages 125-127, Proceedings 2nd International Triticale Symposium, Passo Fundo, Brazil, 1-5 Oct. 1990.

Trethowan, R.M., W.H. Pfeiffer, R.J. Pena, and O.S. Abdalla. 1993. Preharvest sprouting tolerance in three triticale biotypes. Aust. J. Agric. Res. 44:1789-1798.

Trethowan, R.M., R.J. Pena, and W.H. Pfeiffer. 1994. Using line source rain gradients to examine the nature of preharvest sprouting tolerance among three triticale karyotypes and their performance relative to wheat and rye. Aust. J. Agric. Res. (in press).

Varughese, G., T. Barker, and E.E. Saari. 1987. Triticale. Mexico, D.F.: CIMMYT. 32 pp.

Chapter 14.

CIMMYT International Wheat Nurseries

Paul N. Fox

A Strong Tradition in Germplasm Dissemination

The track record of International Nurseries (IN) has been in dissemination of a product-mix of small grain cereals tailored to diverse needs and circumstances of client countries. Almost all CIMMYT germplasm leaves Mexico by air through the auspices of IN and the impact of the germplasm worldwide is testimony to a functional distribution mechanism.

The distribution mechanism consists of two components. The first is the formal nursery system that advertises available materials worldwide and despatches, based on requests, approximately 8 t of seed in 500,000 envelopes each year. The second component consists of miscellaneous shipments, including special requests, nonadvertised nurseries, and materials selected by visitors to CIMMYT's operations in Mexico. The formal nursery system has undergone a degree of rationalization and streamlining in recent years. In 1991, 2413 sets of nurseries were sent, while in 1994 the total was approximately 1630. At the same time, the volume of miscellaneous lines has grown as follows: 1990—28,894; 1991—37,675; 1992—41,706, and 1993—40,866.

Dynamic Innovation

Today's strategy is to maintain this strength in dissemination while addressing a major new challenge: to "add value" to germplasm through information management. As a first step, industrial quality data (and some other performance data) are now sent with the nurseries. An article "The International Wheat Information Initiative" in the 1993 Annual Wheat Newsletter spells out the philosophy and details of this major continuing initiative, which requires significant re-orientation and training of national staff. It is congruent with CIMMYT's mandate for "increasing the productivity of resources committed to maize and wheat while protecting natural resources" and recognizes major changes in the economics of conducting agricultural research.

Specifically, the real costs of field plots are increasing, while the costs of data storage, management, and analysis are decreasing rapidly. Research strategies have not yet recognized these shifting relationships. Conservative estimates are that NARSs collectively invest more than US$1 million per year in field plot management of the germplasm received from the CIMMYT Wheat Program. Data analysis and information exchange relating to IN receives nowhere near such an amount. This implies a concomitant major underinvestment in information technology to make the data generated work for wheat researchers around the world.

As a first step in correcting this imbalance, an international wheat information base will embrace genetic information (conventional and molecular), environmental parameters, and performance data. The system integrates information, which was traditionally handled in isolation, e.g., data from germplasm banks, performance nurseries, and laboratories. Primary keys of the database are the unique identifiers for germplasm and for locations, of which the latter will facilitate interfacing to GIS.

Intense Collaboration

The head of IN was the principal contact from the former Germplasm Improvement Subprogram with the people, organizations, and activities listed in Table 14.1.

Staffing

The staffing trends (Table 14.2), as well as uncertainty in 1994, placed in jeopardy the activities of IN in information exchange and data analysis. CIMMYT must fully either support these initiatives or explicitly resolve to disseminate germplasm without requesting the return of data. There is no viable long-term middle course.

Thirty years ago, seed shipment basically involved treatment, attaching one phytosanitary certificate per shipment, and despatch. Today, individual countries enforce various restrictions

Table 14.2. Staffing trends in IN, 1988-94.

Position	1988	1993	1994
International staff	2	1	0
Graduates	1	0.3	0.9
Nongraduates	5	6	5
Consultants	0	0	1?

Table 14.1. Collaborative activities in IN.

Collaborator	Organization	Activity
Bell	CIMMYT	Variety recommendations for LDCs
Brennan[b]	Australia	Impact of germplasm
Byerlee	CIMMYT	Coefficients of parentage
Butler	CIMMYT	Seed health
CIHEAM	Spain	Statistics for variety evaluation
Clancy	USA	Impact
Collins	USA	IN data analysis
Cooper/Woodruff[a]	Australia	IN data analysis & probe genotypes
Corbett	ICRAF	Historical data rescue
Crossa	CIMMYT	Biometrics
DeLacy	Australia	IN data analysis
Dyke	USA	Data management
Grondona	Argentina	Exptal. design & analysis
Jain	India	Pedigrees
Kephart	USA	GrainGenes
Khairallah	CIMMYT	Cytoplasmic diversity
Maredia	USA	IN data analysis
Mackay[b]	Australia	Data dissemination
Matthews	USA	GrainGenes
Mead	UK	IN data analysis
Muhtar	Canada	Seed disinfection equipment
Mustafa	Pakistan	Multilocation analysis
Romagosa	Spain	AMMI analysis of isogenics
Souza[b]	USA	Coefficients of parentage
Skovmand	CIMMYT	Germplasm bank
SCS	CIMMYT	Software development
Van Beuningen	Holland	Pedigrees
Van den Berg	IRRI	Pedigree Management System
Ward	USA	Data management

[a] Generates some operating costs.
[b] Generates special project funding.

and special conditions falling broadly into two categories: the pathological ones and those related to legal aspects of importation and exportation. The bureaucratic minefield of multiple certification makes increasingly heavy demands on the time of the staff of IN and the Seed Health Unit.

The Future

A 1989 Position Paper on CIMMYT International Wheat Nurseries (in: Fox and Hettel 1992) challenged the "key site" approach to breeding. A parallel position paper to stimulate thinking should be directed towards nursery entries rather than nursery sites. One issue that could be examined, for example, would be the degree of repetition across years of entries in screening nurseries. Another issue to discuss is distribution of non-CIMMYT germplasm once the major vehicle for doing this, ISWYN, is discontinued.

Implicitly, it is believed that yield nurseries have evolved into research tools with screening nurseries increasingly playing the major dissemination role (However, note a series of papers published on data from International Bread Wheat Screening Nurseries, Appendix 14.1). While the impact of germplasm from the CIMMYT Wheat Program is clearly documented, impact is not apportioned among seed received as miscellaneous shipments, regular yield nurseries or regular screening nurseries. Such a breakdown would aid further rationalization of operations and resolve the apparent anomaly of increasing miscellaneous shipments and decreases in the volume of regular nurseries.

IN operations should be more rigorously costed, e.g., shipping costs should separated from supplies in budgeting. Data like the following 1992 shipping costs were never routinely considered: India $10/kg, China $13/kg, and Australia $21/kg. Nonetheless, it is obvious that, per kilogram of seed and per line of wheat, miscellaneous shipments require more labor than regular nurseries, for which the economies of scale in preparation are significant.

The warehouse and seed handling area must be integrated into the electronic communications and computing network. Robotics should be investigated for seed preparation. Seed cleaning machinery in use is obsolete, resulting in the need for manual separation of morning glory seed, which would be easily removed with indent cylinders.

IPR may represent a major challenge. CIMMYT's first agreement with cooperators on wheat germplasm release was drafted after consultation with the Stanford Law School and we hope to show significant advantages of unrestricted data sharing before limitations are imposed.

Further cost savings may involve preparation of yield nurseries in alternate years, as could charging developed countries for freight of their seed.

Reference

Fox, P.N., and G.P. Hettel, eds. 1992. Management and Use of International Trial Data for Improving Breeding Efficiency. Wheat Special Report No. 8. Mexico, D.F.: CIMMYT.

Appendix 14.1. Studies on wheat and triticale using data from CIMMYT coordinated international nurseries.

Refereed scientific journals:			
1974, Anderson	ISWYN6	Rev. Marketing Agric. Econ. 42:131-184	Stochastic dominance
1976, Byth et al.	ISWYN4	Heredity 37:215-230	Pattern analysis
1977, Laing & Fischer	ISWYN	Euphytica 26:129-139	Regression
1980, Menz	ISWYN	Field Crops Res. 3:33-41	Stochastic dominance
1990, Fox et al.	ITYN	Euphytica 47:57-64	Cluster analysis
1991, Crossa et al.	ESWYT8	TAG 81: 27-37	AMMI analysis
1992, Braun et al.	ISWYN	Crop Sci. 32:1420-1427	Correlation
1993, Cooper et al.	IBWSN	Field Crops Res. 32:305-322	Pattern analysis
1993, Cooper et al.	IBWSN	Field Crops Res. 32:323-342	Pattern analysis
1993, Cooper	IBWSN	Field Crops Res. (in press)	Pattern analysis
1994, DeLacy et al.	ISWYN	Euphytica (in press)	Pattern analysis
Other presentations:			
1977, Byth et al.	ISWYN10	Unpubl. report to CIMMYT	Pattern analysis
1979, Phung et al.	ITYN7	Unpubl. report to CIMMYT	Pattern analysis
1980, Worrall et al.	ISWYN	3rd Int. Wheat Conf., Madrid	Regression
1981, Englander	ISWYN	Thesis, Yale University	Regression
1983, Braun	ISWYN	Thesis, Univ. of Hohenheim	Heritability
1983, Fox & Skovmand	ITYN	ASA Washington	Pattern analysis
1983, Skovmand et al.	ITYN	6IWGS Kyoto	Dunnett's test
1984, Pfeiffer	ISWYN	Thesis, Univ. of Hohenheim	Regression
1985, Skovmand et al.	ITSN	Eucarpia Clermont-Ferr.	ANOVA
1985, Fox et al.	ISWYN /ITYN	ASA Chicago	Pattern analysis
1988, Abdalla & Varughese	ITYN	Eucarpia	Regression
1988, Cooper	IBWSN	Thesis, Univ. of Queensland	Heritability
1988, Gilmour	IBWSN10	Thesis, Univ. of Queensland	Heritability
1989, Pfeiffer & Braun	ISWYN	In Variability in grain yields (J.R. Anderson & P.B.R. Hazell)	Regression
1990, Englander	ISWYN	In Research, productivity and incomes in Asian agriculture (R.E. Evenson & C.E. Pray)	Regression
1990, Crossa et al.	ISWYN21	Genotype-by-environment interaction and plant breeding. (M.S. Kang)	Factor analysis
1991, Pfeiffer & Fox	ITYN	2nd Int Triticale Conf. Passo Fundo	Factor analysis
1993, Maredia	ISWYN	Thesis, Michigan State Univ.	Econometrics

Chapter 15.

Quality Improvement of Wheat and Triticale

Roberto J. Peña

Introduction

Until a few years ago, industrial quality (IQ) improvement was considered a breeding goal less important than those dealing with traits associated with productivity. CIMMYT's wheat populations have been showing, on average, only fair IQ, particularly those aimed to high productivity areas of the developing world, where there are yield-quality tradeoffs and the price of wheat is uniform, regardless of IQ. In this case, IQ improvement cannot be justified as a major breeding goal.

Recently, IQ improvement has taken more importance in several wheat breeding programs around the world (CIMMYT 1993). This change in criteria has occurred mainly in countries were wheat production has reached important levels as to make the crop a significant component of the country's economy, and where the wheat markets are being liberalized and wheat IQ receives price premiums. Given this panorama, CIMMYT's Wheat Improvement Subprogram has increased efforts to satisfy its clients' demand for wheat germplasm with acceptable IQ.

In dealing with wheat IQ improvement, bread wheat (BW) and durum wheat (DW) should be treated separately because they are significantly different (species-related) in relation to some physical, compositional, and rheological IQ traits to breed for. The same applies to triticale (Tcl). Therefore, the three crops are treated accordingly.

Bread Wheat

Criteria for IQ improvement

BW is used for the production of baking goods (bread, cookies, cakes, and pastry) and oriental noodles, predominating its usage in the preparation of a very large variety of breads, from flat and dense to bulky and spongy. Differences in BW grain hardness and grain compositional factors, mainly its gluten protein, influence, to different degrees, the quality of the food system and of the finished food product. These IQ-related grain factors are primarily under genetic control and can, therefore, be modified through plant breeding.

In general, when developing criteria for bread wheat IQ improvement, the main uses of wheat, in the particular geographical area of a wheat breeding program, should be taken into account. At CIMMYT, the criteria for bread making quality improvement are based on the fact that BW germplasm is targeted chiefly to wheat producing areas of the developing world where most of the breads consumed are of the medium to low specific volume (v/w) type (Table 15.1). The requirements, on average, are medium-strong, balanced to extensible, gluten types. Therefore, CIMMYT's BW breeding program aims to develop germplasm preferably having from medium-strong to strong gluten type, and from balanced to extensible gluten character. Wheats with tenacious (unexetensible) gluten character have, in general, undesirable bread making properties. Although the breeding program focuses mainly on the improvement of grain factors that influence bread making quality, some attention is also given to the development of soft BW germplasm suitable for cookies, pastry, etc.

Gluten quality is primarily under genetic control, but its expression is affected by external factors such as, in order of importance, climatic conditions, crop management, and diseases. Among these, high rainfall is of particular importance because it promotes grain sprouting (a genotypic trait that compromises gluten and bread making quality due to the production of high levels of enzymatic activity), which results in a drop of the commercial value of the crop. Tolerance to grain sprouting is, therefore, an additional quality trait to breed for in germplasm targeted to high rainfall ME2 and ME6.

Genetic, biochemical, and rheological aspects

Gluten, the main portion of the grain protein, is a water-insoluble complex composed of two major protein groups: gliadins and glutenins, which are under the control of genes located at complex loci in group 1 and group 6 chromosomes. Gliadins contribute mainly to gluten extensibility while glutenins to gluten elasticity, as commonly known, gluten strength. Variations in some gliadins and in glutenins are responsible for the diverse gluten properties of wheat. The contribution of individual gliadin and glutenin subunits is still not well understood, although it has been found (Payne et al. 1981) that the high molecular weight (M_r) glutenin subunit composition, controlled by genes located at the *Glu-A1*, *Glu-B1*, and *Glu-D1* loci, has important bread making quality implications. Recently (1989), the determination of high M_r glutenin subunit composition was adopted at CIMMYT to facilitate the improvement of bread making quality in BW.

Table 15.1. Main bread types consumed in CIMMYT mega-environments (ME)[a]

Mega-Envriroment	Area[b] (%)	Production[b] (%)	Representative Region/Country	Main Bread Type[c]	Volume (v/w)[d]
ME1 Favorable	36.1	42.7	Indian Subcontinent/Mexico/Egypt	Chapati/tortilla/flat bread	Low
			Mexico/Egypt	Bread rolls	Medium
			China	Steamed bread	Medium
ME2 High rainfall	8.5	10.4	WANA	Flat bread	Low
			WANA	Bread rolls	Medium
			Central and South America/Turkey	Bread rolls	Medium
			Turkey	Flat bread	Low
			China	Steamed bread	Medium
			East Africa	Bread rolls	Medium
ME3 Acid soils	1.9	1.3	Brazil/Central Africa	Bread rolls	Medium
ME4 Semi-arid	14.6	6.9	WANA	Flat bread	Medium
			Southern Cone	Bread rolls	Medium
			Indian Subcontinent	Chapati	Low
ME5 Tropical	8.0	6.4	Bangladesh	Chapati	Low
			Paraguay/Thailand	Bread rolls	Medium
			Sudan	Flat bread	Low
ME6 High latitude, moderate to severe cold	24.7	25.6	China/Russia	Bread rolls	Medium
			China	Steamed bread	Medium
ME7 Severe winter	6.2	6.8	Harbin (China)	Steamed bread	Medium

[a] Murgunov and Peña, unpublished.
[b] Source: Rajaram et. al. 1993b.
[c] From Nagao (1981) and Pomeranz (1987).
[d] Classification according to Faridi (1988).

The contribution of gliadins and glutenins to gluten strength and extensibility, are indirectly estimated by measuring parameters such as protein content, SDS-sedimentation, dough strength, and dough extensibility (dough rheology), and by determining the characteristics (crumb structure and loaf volume) of the loaf of bread. Both strength and extensibility (unextensibility is called tenacity) are terms used to refer to wheat, gluten or dough in relation to their bread making quality. In general, breads with high specific volume require strong wheats (wheats with strong gluten), while breads with medium to low specific density require medium strong wheats. In both cases, balanced to extensible gluten types are desirable. These above parameters are interrelated (Table 15.2) and, therefore, serve in the characterization of the bread making quality of BW germplasm.

Breeding for bread making quality at CIMMYT

The introduction and wide spread use of widely adapted but tenacious lines like 8156, Buckbuck, and some of the Veerys in the breeding program was accompanied by a significant drop in the proportion of lines with good bread making quality. By the late 1980s, the proportion of high-yielding germplasm targeted to ME1 with medium-strong to strong, and extensible gluten type was at its lowest.

Ever since grain quality became a major priority in 1990, almost all the crosses made take quality requirements into consideration for a particular ME. Parents are carefully selected while planning crosses. To facilitate selection of parents based on quality, parental material is now grouped into quality groups based on grain hardness, gluten strength, gluten extensibility, and potential uses in baking (Table 15.3). A good proportion of superior bread making quality BW lines is available in various recent ME screening nurseries (Table 15.4).

The determination of the composition of high molecular weight (M_r) subunits of glutenin in BW was initiated in 1989-1990. Recent CIMMYT parental populations include a good proportion of high M_r glutenin subunits with

Table 15.2. Correlation coefficients among bread making quality-related parameters in bread wheat[a].

SDSS[b] vs. W	SDSS vs. Loaf vol.	W vs. Loaf vol.	P/G vs. SDSS	P/G vs Loaf vol.
0.66	0.65	0.60	-0.29	-0.37

[a] Wheat samples (n=1605) from various CB and IBWSN populations.
[b] SDSS, SDS-sedimentation; W and P/G, Alveograph's strength and tenacity/ extensibility ratio, respectively; Loaf vol., bread loaf volume.

Table 15.3. BW classification in relation to quality characteristics and potential end-use in baking.

Quality group	Quality characteristics	End-use in baking
1	Hard Grained. Strong, balanced to extensible gluten	Mechanized breadmaking, pan-type bread, corrector of inferior quality wheats
2	Hard grained. Medium-strong, balanced to extensible gluten	Semi-mechanized bread making, bread rolls, french and flat type breads
3	Soft grained. Weak, balanced to extensible gluten	Cookie making, pastry, steamed bread
4	Hard grain. Medium to weak, tenacious gluten	Cakes, cookies and pastry. Limited use in bread making

favorable quality effects (Morgunov et al. 1993, Peña et al. 1991a). Actually, the germplasm used in crosses mainly possess subunits with positive effect on bread-making quality, such as 1 or 2*, 7+8 or 17+18, and 5+10.

A particular objective of the breeding program regarding glutenin composition is to reduce in CIMMYT germplasm the frequency of the subunits 0 (null allele), 7+9 (introgressed extensively with the Veery's into CIMMYT germplasm), and 2+12, which have a bread making quality effect inferior to that of their above counterparts. Table 15.5 shows that these subunits are in a much higher frequency in BW lines with inferior

Table 15.4. Mean values for quality characteristics of CIMMYT BW populations separated by bread making quality group.

Quality Group[a]	n	SDS-Sediment[b] ml	Alveograph W	Alveograph P/G	Bread Loaf vol. ml
		CB MV-92 (includes ME1, ME2, ME4, ME5)			
1	52	21.0A	353A	4.8A	817A
2	161	18.0A	256B	4.2A	782A
4	345	15.5B	194C	7.6B	666B
		Cand. SN Y.91-92 (includes ME1, ME3, ME4)			
1	86	18.2A	388A	5.4A	892A
2	292	15.0B	255B	4.6AB	846A
4	235	11.7C	196C	7.5C	803B

[a] Quality groups 1 and 2 have strong and medium-strong gluten type, respectively, suitable for bread making. Group 4 has weak to medium-strong, tenacious gluten type, unsuitable for most uses in bread making. The soft wheat quality group (no. 3) was not included.
[b] Mean values in the same column and section followed by the same letter are not significantly different ($p<0.05\%$).

Table 15.5. Distribution (%) of Glu-1 encoded allelic variants in the CB MV-92 population (includes ME1, ME2, ME4, ME5) separated into quality groups.

Alleles	Population total	Distribution within Quality Groups[a] 1	2	4
Glu-A1				
0	**16.6**	**3.8**	**6.8**	**24.1**
1	26.7	44.3	29.8	23.2
2*	56.7	51.9	63.4	52.7
Glu-B1				
7+8	13.5	30.8	11.2	7.5
7+9	**60.0**	**30.8**	**60.9**	**69.2**
17+18	19.8	34.6	21.7	17.0
Glu-D1				
5+10	62.0	92.2	85.7	53.4
2+12	**38.0**	**7.8**	**14.3**	**46.6**

a Quality groups 1 and 2 have strong and medium-strong gluten type, respectively, suitable for bread making. Group 4 has weak to medium-strong, tenacious gluten type, unsuitable for most uses in bread making. The soft wheat quality group (no. 3) was not included.

quality than in those with good quality. Therefore, composition of high M_r glutenins complement efficiently the bread making quality-related parameters in the criteria for selecting parental material for new crosses.

In order to further support breeding for quality, research is being conducted at CIMMYT to examine the possibility of counteracting negative quality effects associated with some 1B/1R translocation wheats by combining particular glutenin alleles (Amaya et al 1991, Morgunov et al. 1993), and to examine the quality effects of glutenins from alien genes (*T. urartu, T. tauschii, T. dicoccon*) introgressed into BW.

Breeding for sprouting tolerance

As indicated earlier, grain sprouting is a trait that invariably upsets the industrial quality of wheat and, therefore, is an important quality trait to breed for, particularly in germplasm targeted to those ME were wheat germplasm is vulnerable to sprouting (Rajaram et al. 1993). In 1988, an aggressive strategy was onset to identify true sources of sprouting tolerance in CIMMYT's germplasm. Three thousand advanced lines were submitted to heavy rainfall past their maturity. From these, 53 sprouting-tolerant lines were identified (Rajaram et al. 1990) and used as parental material in new crosses. Progeny in the advanced stages from these crosses, have been grown in Toluca (high rainfall testing location), and tested for bread making quality-related characteristics as well as for Falling Number, a visocimetric test which measures indirectly (amylase activity in flour) sprouting tolerance. Under this breeding scheme, the breeding program has been able to identify a good number of lines, all red-grained, semidwarfs, showing excellent sprouting tolerance which are suitable for the problem mega-environments (ME2, ME3, ME6, and ME7).

Although breeding for quality was prioritized a few years ago and the major impact from this work is still to come, at present CIMMYT offers a good number of high quality bread wheat lines distributed through international nurseries to diverse mega-environments. This germplasm would satisfy the bread making quality requirements of NARSs, either for breeding activities or for direct varietal release.

Table 15.5. Distribution (%) of Glu-1 encoded allelic variants in the CB MV-92 population (includes ME1, ME2, ME4, ME5) separated into quality groups.

		Distribution within Quality Groups[a]		
Alleles	**Population total**	**1**	**2**	**4**
Glu-A1				
0	**16.6**	**3.8**	**6.8**	**24.1**
1	26.7	44.3	29.8	23.2
2*	56.7	51.9	63.4	52.7
Glu-B1				
7+8	13.5	30.8	11.2	7.5
7+9	**60.0**	**30.8**	**60.9**	**69.2**
17+18	19.8	34.6	21.7	17.0
Glu-D1				
5+10	62.0	92.2	85.7	53.4
2+12	**38.0**	**7.8**	**14.3**	**46.6**

a Quality groups 1 and 2 have strong and medium-strong gluten type, respectively, suitable for bread making. Group 4 has weak to medium-strong, tenacious gluten type, unsuitable for most uses in bread making. The soft wheat quality group (no. 3) was not included.

Durum Wheat

Criteria for IQ Improvement

CIMMYT's criteria for durum wheat (DW) quality improvement takes in consideration, as with BW, the main type of foods prepared in the regions where CIMMYT targets its germplasm. Worldwide, DW is consumed as semolina for the production of alimentary pasta (spaghetti, macaroni, short pasta) and regionally, as flour and coarsely ground grits (coarse semolina) for the production of low specific-volume breads and regional dishes (bulgur, couscous), respectively. Vitreous kernels, medium strong to strong gluten, and high yellow pigment content are the grain compositional factors that satisfy the quality attributes of most of the above DW-based foods (Table 15.6). At present, in addition to efforts to improve traits associated with productivity (yield potential and resistance/tolerance to biotic/abiotic stresses), CIMMYT's DW breeding program aims to improve these quality characteristics, mainly in DW germplasm targeted to ME1 and ME4. In germplasm targeted to ME2, quality improvement is not considered at the moment as important as the enhancement of disease resistances (to rusts, septoria, BYDV, scab, among others).

Genetic, biochemical, and rheological aspects

In DW quality, high semolina yield, high yellow pigment content, and medium to high gluten strength are the main breeding traits. At CIMMYT, the DW quality breeding process starts in early generations, with the selection of individual plants from F2 to F5. Selection parameters include visual assessment of grain size, grain vitreousness and yellow berry; traits strongly associated with semolina yield potential. Next, grain of the selected lines is ground into whole meal flour and screened for gluten strength, as measured with the sedimentation test, and the remaining selected lines, for yellow (carotenoids) pigment content. Parental material and advanced lines belonging to the various screening nurseries are analyzed for flour protein content, sedimentation volume and yellow pigment content. Finally, candidates for varietal release are submitted to full quality analysis, which includes semolina milling, gluten strength, yellow pigment content and pasta (spaghetti) cooking properties.

Table 15.6. Durum wheat food uses in the world and grain quality requirements.

Food Type	Grain Quality requirements	Food Product
Alimentary pasta	Medium strong to strong, gluten. High yellow pigment content.	Long (spaghetti, etc.), short or cut (fagiolini, etc.) and skeins (fettuccine, etc.).
Bread	Medium strong to strong gluten. High yellow pigment content.	Low specific volume bread (leavened and unleavened bread).
Steam-cooked grits (semolina)	Medium strong to strong gluten. High yellow pigment content	Couscous (ingredient of regional salty and sweet dishes).
Cooked grain	High yellow pigment content.	Bulgur (crushed cooked grain; ingredient of regional salty and sweet dishes).

Recently, determination of high and low M_r glutenin subunit composition—allelic variations at the *Glu-B3* locus have been found associated with gluten strength (Payne et al. 1984)—was examined as a potential quality criterion used in DW quality improvement.

Breeding for DW quality at CIMMYT

High quality DW varieties from diverse origins (Canada, Chile, France, Italy, USA, among others) were used in CIMMYT during the early 1970s as parental material to improve the deficient quality characteristics of the DW germplasm. At that time, while the IQ section was efficient at screening for yellow pigment, it could not screen for gluten strength because a rapid small scale test was not available for this purpose. Therefore, improvement of gluten strength had to rely on the selection of parental material having good gluten strength, as judged by a rudimentary gluten hand-stretching test. In the early 1980s, yellow pigment content in the germplasm could be increased significantly, while gluten strength increased modestly (Table 15.7). The latter was due to both, large impact made on yield potential (accompanied with a drop in grain protein) and to the lack of a reliable methodology to screen segregating germplasm for gluten strength.

Important advances on gluten strength improvement (Table 15.7) came few years later, after the reliable small-scale method, the SDS-sedimentation test, was available (1985) to screen for gluten strength. As a result of greater emphasis on gluten strength in DW, the proportion of lines with weak gluten type has been reduced from 26% in the 20th IDSN (1989) to 6% in the 25th IDSN (1993). Now, recent IDSN populations distributed widely among NARSs and cooperators offer a large number of good quality DW lines.

In the mid-1980s, screening for yellow pigment content was applied first followed by screening for gluten strength. Quality screening was done in that order simply because the screening methodology for the first trait was available earlier than for the second one. However, later on the order of quality testing was turned around as it was recognized that gluten strength was a more important trait globally. With this, improvement of yellow pigment content lagged somewhat during the recent years. Some extra effort is needed to up-grade the yellow pigment content in CIMMYT germplasm.

Table 15.7. Quality characteristics DW cultivars grown in NW Mexico during the last 18 years[a].

Cultivar	Yellow pigment (ppm)	SDS-sedimentation (ml)
Jori 69	4.6	11.5
Cocorit71	7.0	9.5
Mexicali 75	6.4	13.0
Yavaros 79	6.6	12.5
Altar 84	8.3	14.5
Aconchi 89	9.0	15.0
Advanced lines (1993)		
Rissa	9.2	16.5
Ajaia	8.0	15.5
Yav/Auk	10.8	18.0

[a] Varieties grown in same location and management (CB Y. 90-91).

Recently, specialized durum quality nurseries (DQN) were formed to ensure enough flexibility in the selection of sources for specific quality traits (grain protein, yellow pigment, gluten strength) separate or combined. DQN lines are being used widely as parental material in new crosses, and will be made available to cooperators in 1994.

In relation to the use of the information on high and low M_r glutenin subunit composition for gluten strength improvement in DW, we examined in 1992 the

distribution of glutenins in recent CIMMYT DW advanced lines as well as the relationship between allelic variations at *Glu-B1* and *Glu-B3* and the sedimentation test. The results showed that over 95% of the lines examined (773) possessed the *Glu-A1* null allele (absence of glutenin subunit), a common situation in cultivated DW. Five *Glu-B1* encoded glutenins were present in variable frequencies, predominating 7+8 over the other subunits (Table 15.8). Most of the lines possessed low M_r glutenin LMW-2 (Table 15.8). This latter finding is more likely due to the intensive selection pressure placed for gluten strength with the sedimentation test, as indicated by the significant relationship observed between these two traits; lines possessing LMW-2 showed much higher SDS-sedimentation volume (regardless of high M_r glutenin composition) than lines with LMW-1 (Table 15.9). Based on the above findings and on those of Peña et al. (1994), it was decided that there was no need to include the determination of glutenin subunit composition in the breeding methodology, since the SDS-sedimentation test has proven to be efficient enough as to select for lines with desirable glutenin composition, and consequently with superior gluten strength. In spite of this, work is underway to look at enhancing gluten strength by introducing favorable high M_r glutenins from within *T. turgidum* or from other alien species.

It is expected that as the genes and/or alleles for desirable quality traits spread out within a larger proportion of the DW germplasm, the parental material involved in new crosses would have satisfactory quality levels as to reduce considerably the large labor input placed on screening thousands of lines at the segregating stage.

Table 15.8. Distribution (%) of high and low M_r glutenin subunits of glutenin in recent CIMMYT durum wheat germplasm (n=773, includes parental material and advanced lines).

High M_r glutenins					Low M_r glutenins	
7+8	20	6+8	13+16	13+19	LMW-2	LMW-1
47.1	25.6	14.9	7.4	5.0	90.9	9.1

Table 15.9. Relationship between 1B-encoded glutenins and gluten strength in recent CIMMYT durum wheat populations.

	Mean SDS-sedimentation (ml)			
	CB[a] Y.90-91		22nd IDSN[a] Y.90-91	
High M_r glutenins	LMW[b]-1	LMW-2	LMW-1	LMW-2
7+8	8.5	15.0	7.1	14.8
6+8	8.4	16.9	7.6	13.5
20	5.8	13.5	6.5	10.9
13+16	8.7	16.0	7.4	15.9
13+19	-	13.7	-	-

[a] CB, Crossing Block; IDSN, International Durum Wheat Screening Nursery.
[b] LMW, low molecular weight glutenin. LMW-1 and LMW-2, are allelic variants at GLU-B3.

Triticale

Criteria of IQ Improvement

When the Tcl breeding program was started at CIMMYT in 1965, breeders aimed to combine the best traits of wheat and rye into a new manmade cereal to increase the world food supply.

Although Tcl is now an established commercial crop, cultivated on about 2.5 million hectares (primarily on marginal lands, where it generally outyields wheat) distributed throughout more than 30 countries, its consumption as a food is very limited (it is used mainly as a feed grain and as forage). The reason for this is that breeders have concentrated their efforts on improving agronomic characteristics and on enhancing disease resistances, while little attention has been given to the improvement of quality traits associated with its industrial quality. In spite of this, in some countries, as the crop expands in area of production, interest in using Tcl as a food grain is increasing. CIMMYT, a major source of spring Tcl germplasm for many national programs, recognizes that the improvement of the industrial quality of Tcl is feasible. By doing so, it could become even more attractive to increase Tcl production more rapidly, particularly on marginal lands, in ME2, ME3, ME4 and ME6, where Tcl (particularly the complete ones) outyields both BW and DW.

Genetic, biochemical, and rheological aspects

Triticale appears more like wheat than rye in terms of grain composition and functionality of the gluten-like proteins. Therefore, it seemed logical to attempt to produce Tcl germplasm with grain characteristics suitable for baking, as a complementary grain compatible with wheat in the manufacture of baking goods. Thus, the criteria on the improvement of the industrial quality of Tcl at CIMMYT has been focused mainly on the improvement of bread making quality-related characteristics. As in the case of bread wheat, reduced grain sprouting is an important trait to breed for in Tcl.

Breeding for bread making quality in Tcl

During the 1970s and early 1980s, most Tcl germplasm was constituted by substitute Tcl, which has chromosome 2R substituted for 2D. This substitution spread out rapidly with the extensive use of Armadillo as parental material. Early in the 1970s, Tcl lines showed, in general, low test weight, very soft grain type, weak gluten, and high susceptibility to grain sprouting. However, intensive quality selection pressure, applied to segregating lines derived from crosses between Tcl x BW, resulted in a gradual increase in the proportion of advanced lines with over all improved quality (**Table 15.10**). By the early 1980s, improved Tcl lines showed test weight, milling potential, and cookie making quality similar to that of BW. Bread making quality, however, although significantly improved, remained inferior to that of good bread making BW varieties

By the late 1980s, there was enough evidence from international yield trails demonstrating that complete Tcl were agronomically superior to substitute Tcls, particularly under marginal growing conditions. Therefore, a gradual shift in the Tcl breeding program towards increasing the proportion of complete Tcl lines changed the ratio of complete:subsitute Tcls from 25:75 in 1985 to 95:5 in 1992. This shift did not affect the gradual improvement in quality traits such as test weight, milling potential and grain hardness, actually the rate of improvement was faster. Unfortunately, the opposite occurred with gluten strength and bread making quality (Table 15.10).

The drop in Tcl bread making quality associated with the shift from substitute to complete type, prompted us to examine biochemical properties of complete and substitute triticale in relation to gluten content, gluten strength, and bread making quality, which could help us to understand the quality problematic. Beltran et al. (1989) and Peña et al. (1990) found that the gluten content in substitute Tcls was slightly higher than in complete ones, but corresponded to only about 70% of that in BW. Although complete Tcls showed stronger gluten type in the Alveograph than the substitute ones, the latter had significantly better gluten extensibility as well as significantly better bread making. Protein solubility fractionation showed that complete Tcls had a higher proportion of insoluble glutenin and a lower proportion of gliadin than the substitute ones (Table 15.11). These differences in protein solubility distribution may have been responsible for the differences in gluten extensibility encountered between these two Tcl genotypic groups. It was also observed that Tcl, in general, contained levels of nongluten protein similar to those of rye and much lower than those in wheat, as previously reported in the literature. This indicated that the low gluten content in Tcl is due to the gluten protein diluting effect of the presence of the rye genome in the Tcl background. Thus, low gluten content, as a genotypic characteristic, appeared as the main limiting factor to improve the gluten strength of Tcl to the levels found in BW.

Table 15.10. Distribution (%) of triticale lines with improved quality characteristics in various ITSNa populations.

Triticale Population	Test Weight (>76 kg/hl)	Flour Yield (>69%)	Grain Hardness (>45%)b	Falling Number (>250 sec)	Bread Loaf vol. (>700 ml)
10th ITSN (Y. 77-78)	2.0	1.6	3.5	9.2	19.8
16th ITSN (Y. 83-84)	14.7	16.0	9.5	22.9	40.7
21th ITSN (Y. 88-89)	46.2	35.0	58.0	56.6	3.5
23th ITSN (Y. 90-91)	64.1	69.8	90.1	-	0.0

[a] ITSN, International Triticale Screening Nursery.
[b] Grain Pearling Index (%). Values below 45% correspond to semi-hard to hard grain texture.

Table 15.11. Mean values for Osborne-type protein solubility distribution of complete and substitute triticales having high sedimentation volume.

Triticale Type	Na Cl-soluble (%)[a,b]	EtOh-soluble (%)	AcOH-soluble (%)	AcOH-insoluble (%)
Complete[c]	30.65A	27.43A	5.92A	32.84A
Substitute[c]	29.76A	32.79B	7.00A	29.29B
Checks				
BW	17.71	24.04	15.82	34.83
DW	18.94	25.42	13.38	38.23
Rye	36.74	28.58	5.54	28.92

[a] Mean values within one column followed by the same letter are not significantly different (a=0.05).
[b] As proportion of flour protein.
[c] Average of four different samples.

The shift in emphasis towards the complete types was accompanied by a significant interest in using Tcl as feed and as forage. Considering that the latter two potential uses and the food uses had different crop quality requirements, the Tcl breeding program was focused on end-use orientation. Food grain types, feed grain types, and forage Tcl types are now handled separately in terms of quality improvement. Food Tcl types are intercrossed aiming to concentrate rather than to dilute (as happened when crossing food with feed Tcl types) quality. Parental material as well as segregating derivatives are still evaluated for quality traits as conventionally.

In an attempt to have a more efficient quality improvement, the influence of high M_r glutenin subunit composition on gluten strength in Tcl was also examined. Peña et al. (1991b) found that the *Glu-B1* allelic diversity in CIMMYT Tcl germplasm was rather limited, predominating subunit 13+19 in poor bread making quality types, and 13+16 in good quality types over other allelic variants. New crosses between BW and food Tcl types have been made, aiming to introduce the good quality alleles 7+8 and 17+18 and hopefully, better gluten quality.

Further, and perhaps more significant, gluten quantity and quality improvement is expected to occur from the introgression of *Glu-D1* encoded glutenins from wheat into Tcl, as suggested by preliminary data comparing the gluten strength characteristics of normal (1RS) and 1DL/1RS translocation Tcls. Lines possessing the latter and other translocations involving 1DL are still in the segregating stage.

References

Amaya, A., R.J. Peña, J. Zarco-Hernandez, S. Rajaram, and A. Mujeeb-Kazi. 1991. Quality (biochemical) characteristics of normal (1B/1B) and translocation (1B/1R) wheats varying in dough stickiness character at two mixing speeds. AACC 76th Annual Meeting. Cereal Foods World 36:701.

Beltran, M.C., R.J. Peña, and A. Amaya. 1989. Comparison of breadmaking quality-related characteristics in complete and substitute triticales. AACC, 74th Annual Meeting. Cereal Foods World 34:769.

CIMMYT. 1993. 1992/93 CIMMYT World Wheat Facts and Trends. The Wheat Breeding Industry in Developing Countries: An Analysis of Investments and Impacts. Singapore: CIMMYT. 52 pp.

Faridi, H. 1988. Flat breads. In pages 457-506, Y. Pomeranz, ed., Wheat Chemistry and Technology. American Association of Cereal Chemists, Inc. St. Paul, Minn.

Morgunov, A.I., R.J. Peña, and S. Rajaram. 1993. Relationship between high-molecular weight glutenin subunits and bread-making quality of F1 hybrids in bread wheat. Eight Int. Wheat genetics Symposium, Beijing, China, July 20-25, 1993 (in press).

Nagao, S. 1981. Soft wheat uses in the Orient. In pages 267-304, W.T. Yamazaki and C.T. Greenwood, eds., Soft Wheat: Production, Breeding, Milling and Uses. AACC, St. Paul.

Payne, I.P., E.A. Jackson, and L.M. Holt. 1984. The association between gamma-gliadin 45 and gluten strength in durum wheat varieties: a direct causal effect or the result of genetic linkage? J. Cereal Sci. 2:73-81.

Peña, R.J., J. Zarco-Hernandez, and A. Amaya. 1990. Comparison of bread making and biochemical (protein solubility distribution and protein electrophoresis) characteristics in complete and substitute triticales. Presented at the 5th Triticale Portuguese Meeting. Elvas, Portugal, June 1990.

Peña, R.J., A. Amaya-Celis, J. Crossa, and S. Rajaram. 1991a. Relationship between functional (Bread making) properties and HMW-glutenin subunit composition in CIMMYT's high yield potential bread wheat germplasm. Cereals and Bread Congress. Paris, June 1-5, 1991.

Peña, R.J., W.H. Pfeiffer, A. Amaya, and J. Zarco-Hernandez. 1991b. High molecular weight glutenin subunit composition in relation to the bread making quality of spring triticale. In pages 436-440, E.J. Martin, and C.W. Wrigley, eds., Proceedings of the Conference Cereals International. Brisbane Australia, September 9-13, 1991. Royal Australian Chemical Institute. Victoria, Australia.

Peña, R.J., J. Zarco-Hernandez, A. Amaya-Celis, and A. Mujeeb-Kazi. 1994. Relationships between chromosome 1B-encoded glutenin subunit composition and breadmaking quality characteristics of some durum wheat (*Triticum turgidum*) cultivars. J. Cereal Sci. (in press)

Payne, P.I., K.G. Corfield, L.M. Holt, and J.A. Blackman. 1981. Correlations between the inheritance of certain high-molecular-weight subunits of glutenin and bread-making quality in progenies of six crosses of bread wheat. J. Sci. Food Agric. 32:51-60.

Rajaram, S., R.P. Singh, W.H. Pfeiffer, M. Albarran, and R.J. Peña. 1990. Preharvest sprouting tolerance in CIMMYT bread wheat germplasm. In pages 213-219, K. Ringlund, E. Mosleth, and D.J. Mares, eds., Fifth International Symposium on Pre-harvest sprouting in Cereals. Westview Press, Boulder, CO.

Rajaram, S., M. Albarran, R.J. Peña, and A. Amaya. 1993. Advances in breeding for sprouting tolerance in wheat. In pages 104-112, M.K. Walker-Simmons and J.L. Ried, eds., Pre-harvest Sprouting in Cereals. American Association of Cereal Chemists. St. Paul, MN.

Chapter 16.

Wheat Improvement Training at CIMMYT

Reynaldo L. Villareal

Introduction and Background

Applied, practical training in agricultural research and production techniques is critically needed in virtually every developing country. Since its establishment in 1966, CIMMYT has maintained and kept its firm commitment to collaborate with national research institutions to improve their research and human resource capabilities and to better address the needs of their client farmers. In this context, CIMMYT has offered a range of educational and training opportunities to agricultural scientists in national research and production programs. The Center's training program was characterized by close working relations between the senior scientists and a limited number of trainees from the developing world. The emphasis of the training experience was on learning-by-doing, primarily on the field, and nearly always at the side of the senior scientists.

This approach to training at CIMMYT was begun in 1943 by the staff of the Rockefeller Foundation/ Mexican Ministry of Agriculture Cooperative Agricultural Program. Initially, a few young Latin American agricultural scientists were invited to spend up to a year with the Mexico-based research staff to participate in ongoing crop improvement and agronomy programs. Methodologies for the breeding and testing of experimental crop materials were developed jointly, and improved lines or populations of germplasm were provided to the trainees upon their departure for use in their research efforts back home. In this way, close and long-lasting personal and professional ties were forged with these individuals. The course of instruction, *per se*, however, was loosely structured and the trainees spent their time doing basically the same things as the senior scientists.

When the focus of CIMMYT's crop programs began to expand beyond Mexico's borders, the number of trainees increased rapidly, and instruction in both Spanish and English was initiated. The complications inherent in offering instruction in two languages to much larger and more culturally diverse groups of trainees required the development of more formalized and detailed training schedules.

Objectives and Purpose

The principal product of CIMMYT's wheat research program is new and improved genetic materials or germplasm. This program has developed particular breeding or crop improvement strategies, as well as research methodologies and techniques, that are well suited to most developing nations. Therefore, the main objectives of the CIMMYT Wheat Improvement Training Program (CWITP) are: 1) to impart research skills and knowledge needed to run a wheat improvement program, 2) to encourage and develop the trainees' ability to synthesize new forms of wheat technology, and 3) to develop positive attitudinal changes among trainees such as increased confidence, motivation and an appreciation of the benefits of team work and interdisciplinary research.

Although trainees learn first-hand about CIMMYT's methods and materials, the purpose of this training is not to transplant CIMMYT's research approach into each national program. Each collaborating national program is independent, and is free to pursue its own wheat improvement strategy and to release new varieties, hybrids, etc., as it sees fit. Rather, the objective is to allow each national program, through the trainees that come to CIMMYT, to borrow as much or as little of the research approach as is useful to that national program. Therefore, the primary purpose is to strengthen national research programs, so they can more effectively utilize new genetic materials from CIMMYT and other national programs, and thereby, make available a continuing flow of new genetic technology to farmers in their respective countries.

Profile of Trainees

The major thrust of CWITP is directed towards middle-level research workers. The trainees tend to comprise very diverse groups, with some common elements in their backgrounds. These common elements largely reflect the selection criteria established by CIMMYT: the new trainees are required to be fully employed, have a BSc or equivalent, have a working knowledge of either English or Spanish, and be less than 35 years of age. Table 16.1 summarizes the four groups that most often characterize CIMMYT wheat improvement in-service trainees.

Course Content

The training course curriculum was developed in response to the needs of client countries. Villareal and Del Toro (1993b) list 64 of the specific skills considered important in a CIMMYT Wheat Improvement course. Wheat Program staff have traditionally combined field, class, and laboratory work to achieve course objectives. A key feature of the courses has been their emphasis on practical experience. Since 1985 an average of 67% of course time were spent in the field and in laboratory practicals. This is important since participant often have a satisfactory level of theoretical knowledge, but are unable to apply this information in the field. For example, trainees can often describe how to make crosses, but cannot satisfactorily perform the emasculation and pollination on the wheat plant. Similarly, a participant may be able to describe the effect of aluminum toxicity on plants, but cannot recognize this problem in the field. In the classroom, our wheat course has little comparative advantage to other institutions, such as universities, in the presentation of theory, but more so in the application of theory to practical wheat improvement research.

Table 16.1. The four groups that most often characterize CIMMYT wheat improvement in-service trainees.

Employer	Education	Age Groups	Language
Established National Program	BSc and MSc	25-30	English and/or Spanish + Others
New National Program	BSc + other crop experience	30+	English and/or Spanish + Others
University Project	BSc/Technical Assistant	25+	English and/or Spanish + Others
Development Project	BSc/Technical Assistant	30+	English and/or Spanish + Others

Table 16.2 shows the approximate percentage of total course time committed to each major topic in the 1993 wheat course. These figures are typical of traditional CIMMYT Wheat Improvement courses.

Course Logistics

The structure of the CIMMYT Wheat Improvement courses was originally based on the wheat life cycle. The wheat courses were 5 to 6 months long, allowing the participants to observe the full growth cycle and participate in all activities necessary for wheat improvement research work. In most years, training courses have begun in the middle of February at the INIFAP station at Ciudad Obregón, Sonora. Participants arrived during the flowering stage of the wheat crop. They planned and made crosses, selected plants, collected data, and harvested breeding materials. Then, in May, participants plan and conduct the planting of materials at El Batan and Toluca. While waiting for the crop to be established, review classes in plant breeding, genetics, plant pathology, agronomy and physiology are conducted. Creation of epidemics in breeding nurseries commenced in June and July. The training course ends around the middle of August. This schedule has allowed greater emphasis on germplasm evaluation and planning phases. Also, these changes have shortened the course while maintaining course objectives and content.

Throughout the course, participants regularly work alongside CIMMYT staff of all disciplines in the field as they conduct research activities. The experience gained: 1) fosters camaraderie between staff and trainees, 2) promotes trainee confidence, 3) increases both competence in and appreciation of field activities, and 4) develops appreciation for the multi-disciplinary approach. To further encourage participation and interest in field work, each trainee is assigned responsibility for various field research activities, normally collection of agronomic data, disease evaluation, harvest and nursery preparation.

Table 16.2. Approximate time allocated for the major course topics in the 1993 wheat improvement course.

Percent time	Topics and Objective
55	**Wheat breeding** Develop breeding objectives and priorities; Review genetics and breeding; Learn breeding methodologies and strategies; Manage breeding program; Describe essential elements of seed program; Multiply and store seeds; Select and classify seeds; Interpret quality data; etc.
20	**Crop protection** Identify, score and diagnose wheat diseases; Explain breeding for disease resistance; Inoculate wheat diseases; Collect, store, and increase inoculum of wheat disease; Propose appropriate methods of disease and insect control; etc.
5	**Genetic resources** Describe the function and operation of the germplasm bank; Explain wheat wide crosses; Describe cytological techniques; Perform embryo culture; etc.
5	**Crop management and physiology** Identify wheat development stages; Describe influence of climate on crops; Calibrate a sprayer; Calculate fertilizer and herbicide rate; Measure and calculate yield and yield components; Visit on-farm trials; Diagnose field problems; etc.
15	**Others** Conduct statistical analysis using computer and interpret results; Use of biotechnology in plant breeding; Make an oral presentation; Be able to list advantages and disadvantages of experimental designs; Use field equipment safely; Learn Mexican history and art; etc.

Source: Villareal and Del Toro (1993c).

Training Methods and Materials

Learning by doing

Emphasis is placed on providing a large dose of hands-on, field-oriented experience to illustrate the practical application of the scientific theory and to be sure the trainee really learns the skill required for wheat improvement work. This training involves a lot of first person association with the senior scientist of the crop program where they learn the dignity of hard work and the joy of a job well done. This is motivation by example.

Team approach

Each trainee is assigned to a work team with a crop interest (bread wheat, barley, triticale, or durum). The trainee stays with a specific crop for at least one crop cycle. The regular contact inherent in this group approach helps reinforce the young researcher's confidence. Also, this day-to-day experience and participation in a dynamic crop breeding program provides trainees a learning opportunity to appreciate the value of an interdisciplinary and cooperative approach in identifying and solving problems. Other elements of this methodology are the close association found with colleagues from other countries and becoming part of the worldwide fraternity of wheat scientists.

Course integration

With the objective of turning trainees into an "army" of wheat improvement specialists. All trainees regardless of areas of specialization (breeder or pathologist) are given the opportunity to work across disciplines at the field level. This process of integration includes all phases of germplasm improvement research, the theory and practice of cereal pathology and important aspects of crop management.

Review classes

Reviews of plant breeding, pathology, genetics, statistics, agronomy, and plant physiology are conducted to ensure that trainees possess a sound theoretical background. Classwork is related to the field work and fitted into field schedules.

Special lectures

Special lectures and seminars are given by eminent scientists who visit CIMMYT, to supplement the field experience of trainees.

Training aids

The training program has a set of books and other materials covering basic plant breeding, genetics, plant pathology, statistics, and crop management. A training manual is also given to serve as general reference of the course. Other CIMMYT publications are also issued. Such visual aids as slides of diseases, hybridization methods, and inoculation techniques are also employed. Upon returning home, the trainees have a basic library for future use.

Course and Trainee Evaluation

In attempts to do a better job in teaching skills needed to conduct a wheat improvement program, the course is evaluated annually to monitor changes in training needs and modify course curriculum and to document training program impact. Importance of topics taught in the course is assessed annually to keep up with changing needs of our diverse clients. Similarly, participants' opinions are solicited to

tailor the course to their individual or group needs. This provides valuable information for topic prioritization and other modifications in the course curriculum. Finally, CIMMYT staff based in the developing countries provide feed-back on skills they consider essential for scientists doing wheat breeding/pathology research. Consequently, this information is used to improve our course.

Among the many methods used to evaluate the participants' competence in the CWITP, graded homework, laboratory exercises, written and practical tests, informal observation, and self-assessment are the most commonly used. Although these methods are used to some degree, experience has shown that some are more useful and/or efficient than others as tools for assessing and documenting immediate impact of this type of training. A study of Villareal and Del Toro (1993b) indicated that self-assessment, theoretical and practical assessments provide an accurate measurement of group competence and change in the CWITP. Both the theoretical and practical assessments allowed direct and objective measures of changes in trainee competence, but they can be time consuming and thus impractical to implement. The self-assessment scheme using questionnaires offers a reasonable alternative because it is easier to administer and appears to be efficient in measuring changes in group competence. The CWITP will continue to employ this method to monitor the changing needs of course participants worldwide. Valuable information gathered through this procedure will continue to be used as a strong basis for modifying the training curriculum and assessing changes in competence and confidence of trainees to demonstrate the skills taught in the course. Differences in evaluations across years serve to inform instructors that something was done better or poorly in a particular course. This can then be used to adjust the organization and implementation of future CWITP courses.

Finally, CWITP instructors will strive to utilize a combination of self, theoretical, and practical assessments in their future training courses. Practical and theoretical examinations, however, will be reduced because of the logistical and manpower problems involved. Use of questionnaires will be continued and strengthened, thus giving trainees greater opportunity to evaluate and influence course content and also to demonstrate their competence in the skills included in the curriculum.

Major Accomplishments

From 1967 to 1993, CIMMYT trained 575 wheat improvement trainees (breeding and pathology) or an average of 21.3 trainees per year (Table 16.3). Regional distribution of participants during the past 27 years of wheat improvement course are also shown.

Table 16.3. Summary of CIMMYT Wheat Improvement Trainees from 1967 to 1993.

Year	Asia	Africa	LatinAmerica	Other Countries	Total
1967	10	0	2	0	**12**
1968-72	41	27	23	4	**95**
1973-77	35	27	26	6	**94**
1978-82	56	21	34	3	**114**
1983-87	57	31	39	6	**133**
1988-92	53	26	28	2	**109**
1993	9	3	6	0	**18**
Total	**261**	**135**	**158**	**21**	**575**

The impact of CWITP on the human resource capacities in the developing world has been substantial. Reports have indicated that breeders and pathologists trained by CIMMYT are active in over 100 national programs, indicating the importance of the CWITP for increasing the research capacity of personnel from crop institutions throughout the world. Similarly, many of the wheat research leaders in national programs today are former CIMMYT trainees and visiting scientists. Independent surveys of those individuals have shown that many consider their training at CIMMYT to be among the most significant professional development phases in their careers. High among the salient aspects identified by former trainees are the practical skills and confidence they acquired in how to design and execute a field research program. Indeed, CIMMYT trainees invariably have a high reputation within their national programs for high motivation and capacity to achieve research and production results.

Current and Future Emphasis

The current and future emphasis of CWITP can be summarized as follows:

- Assess and prioritize training needs of collaborating national programs. On the basis of this analysis, the number of wheat improvement trainees coming to Mexico will be decided. Further integrate plant breeding, pathology, crop management, and related disciplines in the course.
- Continue the involvement of eminent visiting scientists through lectures and seminars.
- Develop training materials to guarantee continuity in training regardless of changes in personnel.
- Intensify the evaluation of trainees' comprehension of technical materials to ensure that the training system is appropriate.
- Implement a follow-up program once trainees return home, with the objective of maintaining communication with fellow researchers and judging the relevance of the training received.
- Develop an advanced wheat improvement course for MSc/PhD degree holders or senior level national program staff from developing countries.

Conclusions

CIMMYT in Mexico provided training to 575 wheat improvement in-service trainees from 80 developing countries between 1967 and 1993. A typical traditional CIMMYT Wheat Improvement course has been described elsewhere (Swanson 1975; Villareal and Del Toro 1993a,c). The CWITP have attempted to teach wheat breeders/pathologists from developing countries how to:

- Determine breeding objectives and organize a germplasm improvement program.
- Identify and describe desirable agronomic traits, physiological problems, insect and disease resistance.
- Lay out, plant and manage nurseries, and obtain and record the appropriate observations.
- Select parental material, make crosses, and select new lines.
- Test and evaluate new lines or cultivars.
- Maintain and multiply pure seed.
- Determine grain quality.
- Organize and operate a pathology program in conjunction with a breeding program.
- Collect and preserve pathogen inoculum, inoculate plants to induce disease epidemics, and ensure uniform disease conditions within breeding nurseries.

- Identify the important diseases of wheat, triticale and barley, and about available corrective or preventive measures.
- Evaluate diseases by type of reaction and by degree of infection in nurseries and commercial fields.
- Identify the virulence of rusts using greenhouse differentials, and how to isolate and identify pathogens in the laboratory.
- Diagnose agronomic constraints to crop production.

The special strength of the course that has evolved over 25 years is its focus on the wheat crop and on farmers' actual conditions, as well as its combination of practice and theory.

The ultimate result of this approach to training is the creation of an international network of scientists involved in the development and release of widely adapted, high yielding, and disease resistant varieties. These are essential components to furthering the production of wheat in the developing world. Finally, many alumni of the CIMMYT training programs have moved into administrative positions within their own national programs. Thus, there is a continuing need to training young promising researchers to replace them, and to maintain a critical mass of knowledgeable and field-oriented wheat scientists.

References

Swanson, B.E. 1975. Evaluation of CIMMYT wheat training program. J. Agro. Edu. 4:85-89.

Villareal, R.L., and E. Del Toro. 1993a. An assessment of a wheat improvement research training course for developing countries. J. Nat. Resour. Life Sci. Edu. 22:38-43.

Villareal, R.L., and E. Del Toro. 1993b. Competence evaluation of participants in a wheat improvement research training course. J. Nat. Resour. Life Sci. Edu. 22:44-48.

Villareal, R.L., and E. Del Toro. 1993c. CIMMYT Wheat Improvement Training Program, 1993 Summary Report. CIMMYT, Mexico. 15 pp.

Chapter 17.

Progress of the CIMMYT-Oregon State University Collaboration

Warren Kronstad, Sanjaya Rajaram, Hans Braun,
Tom Payne, and Maarten van Ginkel

The collaborative program of CIMMYT and Oregon State University focuses on four major activities: 1) germplasm enhancement and dissemination, 2) degree and nondegree training, 3) technology transfer, and 4) the establishment of international linkages among wheat research programs.

Germplasm

Enhancement and dissemination of germplasm result from the systematic probing and merging of the spring and winter gene pools. CIMMYT scientists in Mexico concentrate their efforts on transferring desired genetic factors found in winter wheat into spring wheat backgrounds. OSU and the CIMMYT Program in Turkey do the reverse in enhancing winter and facultative wheat germplasm. Following the exposure of segregating populations to various abiotic and biotic stresses and selecting for agronomic and quality traits, advanced lines are sent as screening nurseries to more than 150 national programs where either spring, facultative, or winter wheats are grown. National programs use this enhanced germplasm as parental sources or to increase and release as new cultivars. The screening nurseries also serve as surveillance nurseries where changes in disease or insect populations and other stresses can be monitored and new sources of resistance or tolerance identified.

A unique shuttle breeding approach has emerged from this program. In Oregon, promising early maturing F3 lines are selected and sent to both the CIMMYT programs at Toluca, Mexico, and Ankara, Turkey. Following one or two cycles of selection at these sites, the more promising lines are returned to Oregon for subsequent crossing or for distribution to cooperators in the form of a screening nursery. Such a procedure has resulted in a wide range of materials with both general and specific adaptation. It has also been effective in building parental materials for desired traits, i.e., disease and insect resistance, day length insensitivity, etc. In addition, the OSU program increases and distributes the facultative winter wheat observation nursery to 25 U.S. breeding programs. This nursery is the product of the CIMMYT program in Turkey.

Since Turkey is on record as a flag smut country and with the U.S. having a zero tolerance for this disease, it is necessary to have a special permit to import seed. Thus, over time, between CIMMYT and OSU, a highly effective means of enhancing and distributing superior spring, facultative and winter wheat germplasm has evolved. The impact of this program can be found in the 1992/93 World Wheat Facts and Trends: The Wheat Breeding Industry in Developing Countries: An Analysis of Investment and Impacts.

Training

Degree and nondegree training is an integral part of the Spring/Winter Program. For many years, CIMMYT/Mexico has conducted a "hands-on" educational experience for young scientists of

improved crop production. At OSU, both nondegree short courses for senior scientists and graduate programs leading to M.S. and Ph.D. degrees are available in various disciplines related to increasing food quality and production. Drs. R.A. Fischer, S. Rajaram, and M. van Ginkel of the CIMMYT staff serve as members of the OSU graduate faculty. This has provided an opportunity for students to complete their courses at OSU and conduct thesis research in Mexico or in their home country. Many of the students receiving advanced degrees at OSU were graduates of the CIMMYT training program before enrolling at OSU. Over 100 scientist have received their graduate training as part of this international program. Today, many of these former students have and are now distinguishing themselves as presidents and deans of universities, department heads, decision makers at various levels in governments, scientists at international centers, and researchers, teachers, and extensionists in many national programs.

Technology Transfer

Transfer of technology has been accelerated by screening nurseries, exchange of information and training of students, including nondegree short courses for scientists and decision makers from developing countries, and especially on-site interactions by CIMMYT and OSU scientists with counterparts in national programs.

A very positive aspect has been the in-country symposia held in countries like Peru, Tunisia, and Argentina. During such meetings, formal presentations by local scientists and staff from OSU and CIMMYT focus on all aspects of cereal production. Following the meetings, a tour of the research activities at key locations in the respective countries is conducted and a report in the appropriate languages is developed, which include the formal presentations, observations, and recommendations. A significant result is that, for the first time, governments and universities recognize mutual problems and plan joint research projects.

Another and quite different means of technology transfer between U.S. universities and international centers involves the development of information from more basic research to solve applied problems. Many examples can be cited including aluminum toxicity screening techniques, microcomputer software for breeding programs, breeding strategies, the development of molecular markers for such attributes as stripe rust resistance in barley, etc.

Linkages

Even prior to the recent normalization of relations with countries in Eastern Europe, Russia, the former republics of the USSR, and The Peoples Republic of China, distribution of the international screening nurseries had already established linkages for sharing germplasm and information. These linkages and their expansion have never been as important as they are today. In an increasingly hungry world, free exchange of genetic materials is critical—especially with more countries adopting intellectual property rights, utility patents, and various forms of plant variety protection laws. International centers like CIMMYT have a very significant role to play in the sharing landrace populations found in developing countries with breeding programs in the so-called "developed" countries so that all parties involved benefit from such exchanges.

Chapter 18.

Wheat Breeding Progress in China

Chongyi Wang
Chinese Academy of Agricultural Science, Beijing

Wheat Production in China

China is the world's largest wheat producer. Wheat is the second main food crop after rice and used mostly to make steamed bread and noodles. During the 1949-1989 period, China's wheat production area increased more than 30% to nearly 29 million hectares, average yield rose from 0.65 to 3.15 t/ha, and wheat production increased more than six-fold to some 85 million tons. In both 1992 and 1993, wheat production exceeded 91 million tons.

Wheat is grown in 29 of China's 30 provinces, however, more than 90% is produced in 13 provinces and four of these (Henan, Shandong, Jiangsu, and Hebei) contribute 50%. Spring-habit wheats are the most common types grown in China (60%), planted both in autumn and spring. Facultative and winter types contribute to 40% of the wheat area.

The Chinese Academy of Agricultural Sciences (CAAS) has divided the country's wheat area into 10 major agro-ecological zones based on wheat type; varietal reaction to temperature, photoperiod, and moisture; and growing seasons:

Zone I. Northern Winter Wheat Region.
Zone II. Yellow and Huai River Valleys, Facultative Wheat Region.
Zone III. Middle and Low Yangtze Valleys, Autumn-sown Spring Wheat Region.
Zone IV. Southwestern Autumn-sown Spring Wheat Region.
Zone V. Southern Autumn-sown Spring Wheat Region.
Zone VI. Northeastern Spring Wheat Region.
Zone VII. Northern Spring Wheat Region.
Zone VIII. Northwestern Spring Wheat Region.
Zone IX. Qinghai-Tibetan Plateau, Spring-Winter Wheat Region.
Zone X. Xinjiang Winter-Spring Wheat Region.

For more details on wheat breeding in China, see He and Chen (1992).

China-CIMMYT Shuttle Breeding Project

In the early 1970s, CIMMYT germplasm was obtained from Pakistan and Mexico. In the middle 1970s, Chinese scientists visited CIMMYT and selected numerous lines. These materials were screened and introduced in the spring wheat regions, some of them such as Alondra, Cajeme F71, Mexipak 66, Sonora 64, Chapingo F74, Saric F70, Siete Cerros, and Potam S70 performed well and were used directly as commercial varieties in production. CIMMYT wheats are grown over large areas of the spring wheat regions, especially in Yunnan Province and Xinjiang Autonomous Region. During the 1950 to 1990 period, 12 of the 51 leading varieties in Yunnan Province were introduced from Mexico/CIMMYT. Siete Cerros made up 20% of the total wheat area in Xinjiang in 1985.

In general, CIMMYT wheats have short stems for good lodging resistance, high yield potential, and good disease resistance (rusts and powdery mildew). However, they are poorly adapted to humid environments as shown by their susceptibility to head scab and early leaf wilting. This has somewhat limited the popularity of CIMMYT wheats in China in some areas.

Remarkable progress has been achieved with crosses made between CIMMYT and Chinese wheats. For example, Kefeng 3 and Kefeng 4, derived from Ke71F4-370-7/Mexipak 66 and Ke71F4-370/Nadadores, respectively, became the leading varieties in Heilongjiang Province, reaching 70,0000 ha annually for both. In the 1980s, CIMMYT scientists visited China and to consult with their colleagues in the Chinese Wheat Improvement Program. CIMMYT also started receiving Chinese trainees and visiting scientists. Many institutes in China requested CIMMYT International Nurseries. In 1988, the Chinese Academy of Agricultural Sciences (CAAS), the leading agricultural research organization in China, signed a formal agreement with CIMMYT that set up a cooperative shuttle breeding project. It focused on the integration of scab resistance of Chinese wheats into high yielding CIMMYT germplasm and the development of germplasm for China. Germplasm (winter and spring) and information exchange and training for Chinese wheat scientists were also included in the project. The Jiangsu, Sichuan, and Heilongjiang Academies of Agricultural Sciences, located in Zones III, IV, and VI, respectively, are directly involved in this project with CIMMYT. These three provinces have 20% of China's wheat sowing area and 20% of its production.

The breeding objectives are high yield potential, early maturity, sprouting tolerance, and resistance to head scab, powdery mildew, and the three rusts. However, some degree of photoperiod sensitivity and pre-anthesis drought resistance are required in Heilongjiang, which is located in the high latitude zone.

Progress

New varieties or advanced lines of spring wheat

Jiangsu Province—Ningmai 7, released in 1993 was developed by the Jiangsu Academy of Agricultural Science in cooperation with CIMMYT. It has high yield potential, lodging resistance, moderate resistance to head scab, and early maturity. Maturing two days earlier, it outyields the check variety Yangmai 5.

Sichuan Province—SW89-2089, a derivative of Genaro 81, has passed the Sichuan Provincial Yield Trials. SW89-1862 and SW90-1648, derived from Veery'S' and Seri 82, respectively, and have been included in the Provincial Yield Trials. SW89-5193 and SW89-5422, both derived from Alondra'S', are being screened in the Provincial Quality Wheat Trials. Some of these lines, cooperatively developed by Sichuan Academy of Agricultural Sciences and CIMMYT, are expected to be release in the next few years.

Heilongjiang Province—CIMMYT germplasm has been widely used. Between 1981-90, 29 of the 37 released varieties were derived from CIMMYT x Chinese crosses. Presently, 90% of the wheat area is covered by varieties containing CIMMYT germplasm. The derivatives of CIMMYT wheats contributed more than 1 million hectares in this province each year and has enhanced the improvement of wheat production. Farmers are now growing the newly released varieties Longmai 15 and Longmai 16, cooperatively developed by CIMMYT and the Heilongjiang Academy of Agricultural Sciences.

Winter and facultative wheats

Winter and facultative wheats share around 40% of the total wheat area in China. Several groups of scientists were invited to visit winter wheat programs in Mexico, USA, and ICARDA. They selected germplasm to use in the breeding programs to enhance yield and quality improvement. A large number of crosses of Chinese winter x CIMMYT spring are being made each year. A winter wheat line, Dongfeng I, selected at the CIMMYT wheat breeding program in Syria, performed very well in the regional and provincial yield trials over the last the last three years. Subsequently, it was released in 1994 in Beijing and Hebei.

Germplasm exchange

Over the last several years, around 500 Chinese commercial varieties, advanced lines, and some very important scab-resistant germplasm, both winter and spring types, were sent to CIMMYT. Chinese spring wheat performed very well, especially showing good resistance to Karnal bunt, head scab, Helminthosporium, and septoria. Many CIMMYT x Chinese crosses are made each year at CIMMYT. Many Chinese derivatives are included in CIMMYT International Nurseries, which are distributed throughout the world. Breeders recognize the yield potential, rapid grain-filling, and early maturity of Chinese winter and facultative wheats are widely. Crosses of Chinese winter x CIMMYT spring wheats are made each year to raise the yield potential of CIMMYT spring wheats. Chinese breeders obtained around 5500 lines from CIMMYT when they were invited to participate in the shuttle breeding project at CIMMYT. This germplasm is playing an important role in Chinese breeding programs.

Training

During the last six years, more than 30 Chinese scientists attended CIMMYT Wheat Improvement Training Courses and participated in the shuttle breeding project. This improved their scientific skills and understanding of the CIMMYT breeding program. Several of the trainees were promoted to head the breeding programs or become the directors and associate directors of their institutes.

Information exchange

Chinese scientists have used CIMMYT publications and CIMMYT has provided a channel for Chinese scientists to become aware of wheat breeding methodologies in other countries. Several CIMMYT publications have been translated and published in China. A book concerning Wheat Breeding at CIMMYT, written by Chinese Scientists at CAAS, was published late in 1994.

Conclusions and Proposals

Since the shuttle breeding project has benefited both sides and considerable progress has been achieved during the last six years, it was suggested that the Chinese-CIMMYT partnership be strengthened and the shuttle breeding project should be renewed. It normally takes around 10 years to release a wheat variety in China, therefore, more significant achievement could be obtained from this cooperative project in the next 5 to 10 years. As China is moving to a market economy, good quality wheats are urgently needed. Industrial quality research in China started only 10 years ago and so it is still pretty much in its infancy. Based on the performance of CIMMYT spring x Chinese winter or facultative wheats, there is great potential in using CIMMYT spring wheats to improve Chinese facultative and winter wheats. Therefore, more attention should be given to training for quality analysis, cooperative research in quality improvement, and shuttle breeding in winter and facultative wheats.

Reference

He Zhonghu and Chen Tianyou. 1992. Wheat and Wheat Breeding in China. Wheat Special Report No. 2. Mexico, D.F. CIMMYT. 14 pp.

Chapter 19.

Wheat Breeding Progress in Brazil

Ricardo G. Matzenbacher
FUNDACEP/FECOTRIGO, Cruz Alta, Brazil

Introduction

Brazil has three distinct wheat growing regions: 1) the colder southern region, including the states of Rio Grande do Sul, Santa Catarina, and southern Paraná; 2) the southcentral region, northern Paraná, southern São Paulo, and Mato Grosso do Sul; and 3) the central region, including Goias, Mato Grosso, Minas Gerais, Bahia, and Federal District, in the Brazilian "Cerrado".

Most Brazilian soils (around 70%) are acidic, with a natural pH ranging from 4.0 to 5.5. They contain toxic aluminum and, in some cases, manganese and iron as well. These soils are also characterized by low phosphorus availability. These conditions limit the yield potential of wheat and other agricultural crops.

Since the beginning of the century, breeders knew there was genetic variability among Brazilian wheat cultivars for resistance to toxic aluminum and phosphorus extraction ability, so they began selecting for these traits.

Although the early Brazilian wheat varieties showed tolerance to aluminum on the positive side, on the negative side they had a very long growing cycle, were very tall, had poor agronomic type, had poor industrial quality, and were susceptible to most important diseases.

The genetic improvement programs in the Brazilian wheat growing regions have released important varieties such as Frontana in 1942, BH1146 in 1946, IAS 20-Iassul in 1963, IAC 5-Maringá in 1966, and IAS 54 in 1970. These varieties were considered benchmarks of productivity in their time, even though they yielded no more then 1 t/ha. Hettel (1989) provides a detailed history of wheat breeding in Brazil.

The growth of soybean production in the country during the late 1960s brought about the need to lime soils to eliminate aluminum toxicity and improve soil fertility. This led to increase wheat yields. These changes occurred at the same time the Brazil-CIMMYT Cooperative Program started.

Brazil-CIMMYT Shuttle

The use of CIMMYT germplasm by the various wheat improvement programs and the implementation of shuttle breeding led to a slow but continuous change in the profile of the Brazilian varieties in all of the wheat producing states (Figures 19.1 and 19.2). Figure 19.1 clearly demonstrates a 100% yield increase since the 1960s. The first results of the Brazil-CIMMYT shuttle began to appear in the 1980s. Figure 19.2 shows that, in the more traditional wheat growing regions (Rio Grande do Sul, Paraná, and São Paulo), yield gains were about the same. Under the higher temperatures of Mato Grosso do Sul, yield gains were not very significant. The "Cerrados" region showed higher productivity, but only a small area is cultivated to wheat here.

The cooperative program between CIMMYT and Brazilian institutions, which began in the 1970s, was characterized by interchange of fixed materials and simultaneous selection in the same segregating populations in both Mexico and Brazil (Hettel 1989). Brazilian wheats resistant to aluminum were crossed with the high yielding, semidwarf Mexican wheats. In Brazil, breeders selected for aluminum tolerance and resistance to a complex of spike and foliar diseases. In Mexico, the same segregating populations were selected for agronomic type and resistance to leaf rust and stem rust.

Through this process, thousands of lines were developed and evaluated resulting in the release of more than 150 varieties over the last 15 years. Table 19.1 shows the important input of Mexican germplasm and the shuttle breeding program. For example, in Paraná, 47 of 70 varieties recommended since 1980 are connected to the Brazil-CIMMYT program. Table 19.2 shows the shuttle connection of 137 varieties

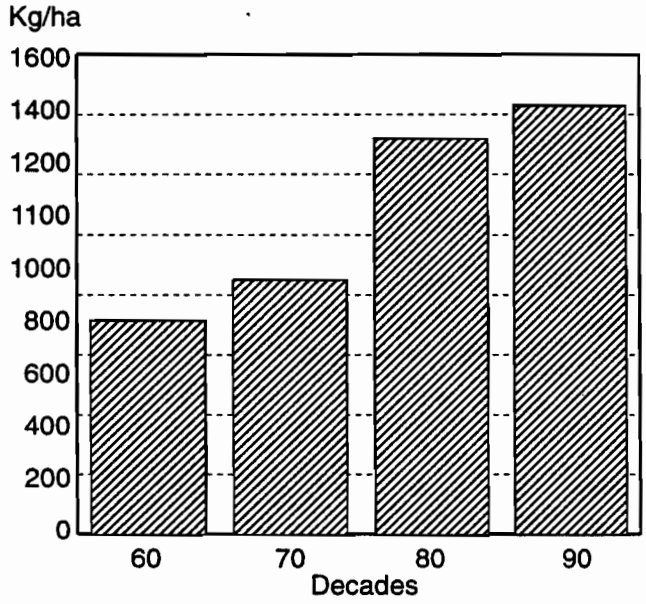


Figure 19.1. Increase of average Brazilian wheat productivity by decade.

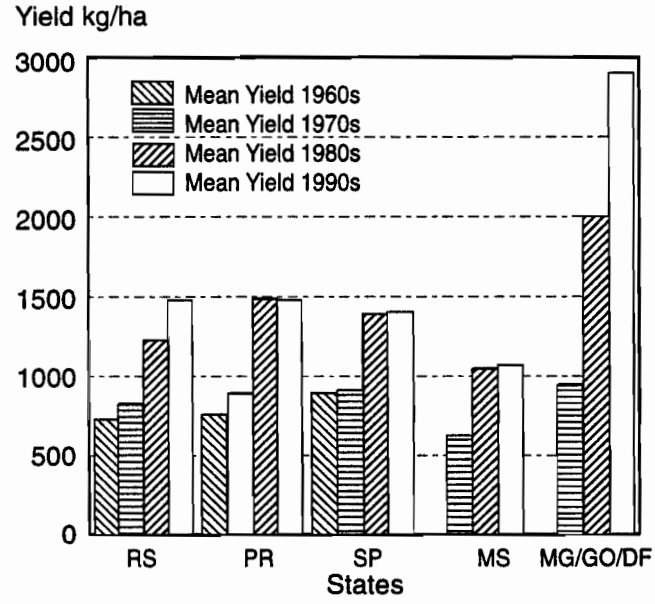


Figure 19.2. Mean wheat yield in the major wheat producing states by decade.

Table 19.1. Wheat varieties recommended since 1980 in the main producing states and their connection (%) with the Brazil-CIMMYT shuttle.

	States									
	RS	**(%)**	**PR**	**(%)**	**SP**	**(%)**	**MS**	**(%)**	**CB**	**%**
Recommended varieties	**32**	**-**	**46**	**-**	**24**	**-**	**26**	**-**	**17**	**-**
Shuttle Breeding Varieties	12	38	47	67	15	63	24	92	16	94
•CIMMYT origin varieties	0	0	22	31	8	33	15	58	9	53
•Varieties from crosses with CIMMYT's material and/or Mexican selection	12	38	25	36	7	30	9	34	7	41

RS: Rio Grande do Sul; PR: Paraná; SP: Sâo Paulo; MS: Mato Grosso do Sul; CB: Central Brazil.

recommended for release in 1993. Table 19.3 shows the effects of shuttle breeding on varieties released for acidic and nonacidic soils. Even though the average Brazilian yields are still relatively low, experimental data from different regions of the country show great potential. Promising lines are averaging around 4 t/ha in Rio Grande do Sul, 4.5 t/ha under irrigation and 3.2 t/ha without irrigation in São Paulo, 4.4 t/ha in aluminum-toxic soils of Paraná, and 5.4 t/ha under irrigation and 2.6 t/ha without irrigation in central Brazil.

Outstanding farmers, who have adopted technologies such as no tillage, crop rotation, adequate fertilization, and chemical control of diseases, have obtained mean yields higher than 2.5 t/ha over the last few years. Yield gains of the new varieties over traditional ones such as Maringá have been more significant in the south due to lower temperatures.

Backcrossing with high yielding varieties as recurrent parents and adapted material that is tolerant to aluminum toxicity has proven to be an effective breeding tool according to data from São Paulo (Table 19.4).

Table 19.2. Number of wheat varieties recommended in 1993 in the main producing states and their connection (%) to the Brazil-CIMMYT shuttle.

	States									
	RS	(%)	PR	(%)	SP	(%)	MS	(%)	CB	%
Recommended varieties	**23**	**-**	**46**	**-**	**23**	**-**	**29**	**-**	**16**	**-**
Shuttle Breeding Varieties	10	43	31	67	12	52	24	83	14	88
• CIMMYT origin varieties	0	-	15	32	8	35	10	35	8	50
• Varieties from crosses with CIMMYT's material and/or Mexican selection	10	43	16	35	4	17	14	48	6	38

Abbreviations in Table 19.1.

Table 19.3. Effect of the Brazil-CIMMYT shuttle on the development of wheat varieties in Brazil, 1984-93.

Bredding results	Acid soil	Non-acid soil
Total varieties released	73	24
Varieties from Brazilian crosses	63	1
Varieties from CIMMYT crosses	10	23
Varieties with all Brazilian selections	50	2
Varieties with one or more CIMMYT selections	23	22
Varieties carrying CIMMYT progenitor in cross	41	24

Source: M.M. Kohli, pers. comm.

Table 19.4. Average yield of recurrent parents and selected Al-tolerant backcross progeny in acid and non-acid soils, Sao Paulo, Brazil, 1992.

	Average yield (kg/ha)	
Variety	Acid soil	Non-acid soil
Anahuac	1,527	3,350
ANA*3/BH 1146	2,387	2,951
IAPAR 17-CAETE	1,480	3,127
CAETE*3/BH 1146	3,580	3,959

Source: M.M. Kohli, pers. comm.

Attributes of the new cultivars

The Brazil-CIMMYT shuttle has led to profound changes in the profile of Brazilian wheat varieties. One hundred and thirty varieties recommended between 1980 and 1993 have the following attributes.

Height—Forty-eight semidwarf varieties were recommended, representing 37% of the total; 53 cultivars (41%) are intermediate and 29 (22%) are tall.

Aluminum tolerance—The use of CIMMYT germplasm did not reduce the level of aluminum tolerance in Brazilian cultivars. For example, this is shown in Paraná where 70 cultivars were released between 1980 and 1993 of which 67% contain CIMMYT germplasm:

Resistant—33 cultivars (47%),
Moderately resistance—15 cultivars (21%),
Moderately susceptible—4 cultivars (6%),
Susceptible—18 cultivars (26%).

Diseases—Even though significant advances have been made in yield potential and agronomic type, there is much to be achieved in the area of disease resistance. This is due to the great variability of the Brazilian climate, which favors constant changes in the pathogen populations. Chemical control, a common practice in Brazil, has led to more stable productivity.

Cycle—In general, the new cultivars are of the early maturity group.

Agronomic type—In addition to reduced height, significant improvements have been made in straw strength, spike size, and fertility.

Industrial quality—The Mexican materials have contributed to a general improvement in this trait.

Other important aspects—Other important aspects have to be taken into account when evaluating the results of the Brazil-CIMMYT shuttle. These include:

- Higher genetic potential of the varieties;
- Proper soil management (minimum- and noti-llage);
- Better fertilization;
- Crop rotation in some regions;
- Chemical control of important diseases, such as foliar blights, powdery mildew, leaf rust, stem rust, and scab;
- Weed control;
- Insect control (aphids and caterpillars).

In spite of the advances made in wheat production, some factors still affect the efficiency of genetic improvement in Brazil, particularly in the warmer areas:

- Restricted genetic variability in the adapted germplasm;
- Restricted variability to disease resistance;
- Lack of drought tolerance;
- Poor phosphorus extraction efficiency.

Even with the improvement of wheat in Brazil, farmers, due to the lack of incentives provided by the Federal government, are ceasing to grow wheat when the market price does not cover the cost of production. Figure 19.3 shows the trends in wheat production, consumption, and importation for the 1970-93 period. Figure 19.4 compares local prices paid to farmers with the cost of imported wheat. As a rule, highly subsidized wheat from countries of origin is cheaper than wheat produced by Brazilian farmers.

Karnal Bunt Problem

Since 1990, the Brazil-CIMMYT shuttle has been interrupted due to the occurrence of Karnal bunt (*Tilletia indica*) in Mexico. EMBRAPA, the official Brazilian research institution, through its Genetic Resource Center (CENARGEN), has imposed a quarantine on all Mexican seed coming from Ciudad Obregón. The disease has not been identified in Brazil. The genetic improvement programs of FUNDACEP, OCEPAR, IAPAR, and IAC, which have worked closely with CIMMYT in the shuttle program, have faced a serious loss of efficiency since the cooperative program was stopped.

Adoption of No-Tillage

Brazilian agriculture is going through a revolution with the adoption of a no-tillage sowing system and the various technologies related to the system. Some 2.5 million hectares are now cultivated under no-till in the country. South central Paraná and the Cruz Alta region of Rio Grande do Sul are now the two most important no-tillage areas. In the 1993-94 summer cycle, Cruz Alta farmers grew 70% of their

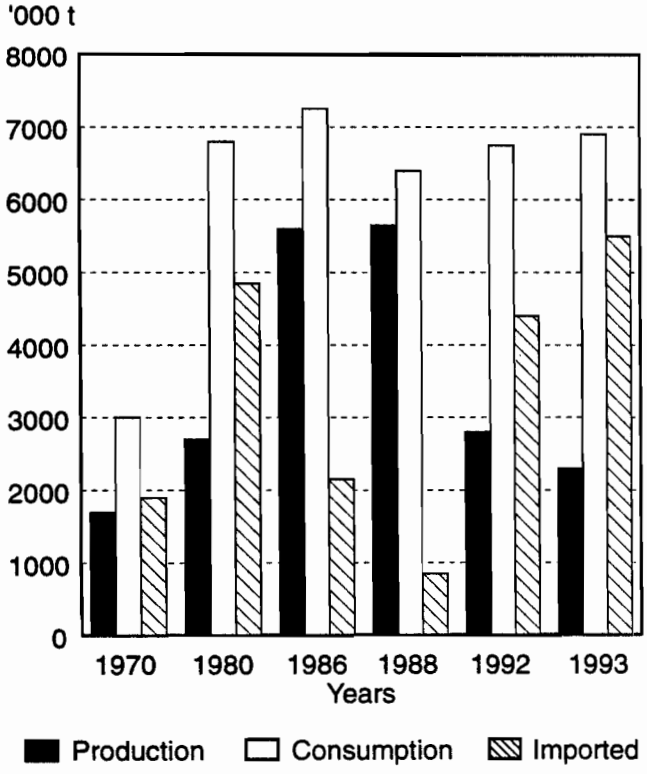


Figure 19.3. Wheat production, consumption, and importation trends in Brazil, 1970-93.

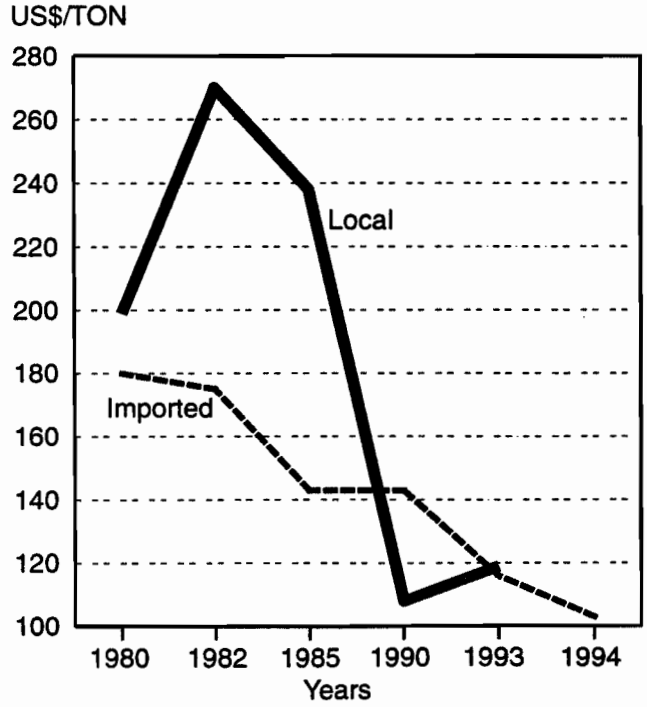


Figure 19.4. Comparison of local prices paid to farmers with the costs of imported wheat for the period 1980-94.

120,000 hectares under no-till. This technology, which makes it imperative to use crop rotation, seed treatment, and other practices, eliminates erosion, increases soil fertility, and allows higher yields. There is a growing need for wheat germplasm adapted to this new practice. Therefore, we believe that use of CIMMYT germplasm and continuation of the shuttle program are more important than ever to give a boost to wheat production under the current circumstances.

To date, maize and soybeans have benefitted the most from no-till. However, wheat has shown productivity gains from no-till as well even though the available germplasm may not be well adapted to the new circumstances. Using averages of the 1985-93 period, productivity gains for maize, soybeans, and wheat were 27, 13, and 6.4%, respectively, under no-tillage compared to conventional tillage.

Studies with maize and soybeans show that root systems of plants under no-tillage develop better. Studies with wheat are just beginning, but similar results are expected. Twenty years ago, Dr. Borlaug observed poor root development when selecting wheat plants in Brazil even in soils where lime was applied to eliminate the aluminum problem. Borlaug pointed out the possibility of a relationship between poor roots and the low yields of the Brazilian varieties. After so many years, we are about to find out if Borlaug's assertions are indeed valid. The improvement of the physical, chemical, and biological soil characteristics through no-tillage will undoubtedly significantly increase crop productivity levels.

Farmers in the Brazilian Cerrado, with a total potential agricultural area of 50 million hectares, are also adopting no-tillage. Without any doubt, this is the challenge of the next century. In the Cerrado, even though it has mostly natural acid soils that must be limed, the great majority of the recommended wheat varieties (Tables 19.1 and 19.2) are in some way related to CIMMYT.

Conclusions

Over the last decades, wheat breeding progress in Brazil has been highly positive. The cooperative work between CIMMYT and the Brazilian research institutions has been extremely important.

The results show a significant yield gain in the southern traditional (cold) wheat growing region (Rio Grande do Sul, Santa Catarina, and Paraná). The use of high yielding semidwarf Mexican germplasm in crosses with the aluminum resistant Brazilian varieties have resulted in the release of higher yielding, improved cultivars.

In the warmer regions where disease incidence is higher, the results have not been as impressive, but there have been real productivity gains. The extraordinary advance of the no-tillage system with crop rotation is bringing about an increase in productivity in both acid and nonacid soils. The fantastic agricultural frontier of the Cerrado may play an important role in the country's economic revival. Irrigation will be important in this region.

After stating all of the above, the following is evident:

- The integration between the Brazilian research institutions and CIMMYT through shuttle breeding must not only continue, but it must be intensified. It would be impossible to measure the negative impact if this cooperative work ceases.
- The Mexican germplasm will continue to increase the yield potential while maintaining the level of aluminum tolerance.
- There is a need to incorporate more resistance to foliar blights, leaf rust, scab, and blast in the Brazilian varieties.
- Improvement in industrial quality is of utmost importance.
- From now on, the genetic improvement programs should be conducted in conjunction with no-tillage systems.

Reference

Hettel, G.P. 1989. Wheat Production Advances in South America's Colossus: The Gains from 20 Years of Brazilian/CIMMYT Research Collaboration. CIMMYT Today No. 18. Mexico, D.F.: CIMMYT.

Chapter 20.

Economic Impacts of Wheat Improvement Research and Efficiency Issues in Investment in International and National Wheat Breeding Programs

Derek Byerlee

This note provides summaries of results of several recent studies on international wheat breeding research. Part I summarizes a study by Byerlee and Moya (1993) on the impacts of international wheat improvement research, with emphasis on CIMMYT's contribution. Part II presents results of recent studies by Maredia and Byerlee (1995), Bohn and Byerlee (1993), and Byerlee (1994) on investments in and efficiency issues in wheat improvement research by CIMMYT and NARSs.

Part I. Impacts of Investment in International Wheat Improvement Research: The Contribution of CIMMYT

The study by Byerlee and Moya (1993) describes and analyzes the impacts of wheat breeding research in the developing world by national agricultural research systems (NARSs) and the International Maize and Wheat Improvement Center (CIMMYT). It gives particular attention to trends in NARSs' use of CIMMYT's germplasm products in the "post-Green Revolution period" since about 1975. In this period, newer semidwarf wheat varieties have replaced most of the original semidwarf varieties in farmers' fields. The economic benefits of those varieties to farmers and society, especially with respect to yield gains and disease resistance, are estimated.

Data collected

The study is based on data collected in 1990-91 from 38 collaborating wheat research programs. As part of the study, all varieties released by NARSs since 1966 were listed, along with associated information on pedigree, ecological niche, and so forth. The area planted with specific varieties in 1990 was also estimated. Altogether, more than 1,300 varieties were listed in this data file. In addition, data were collected from many sources to estimate the rate of genetic gains in yield for varieties released since 1966, as well as changes in other traits, such as disease resistance and quality. The database provides comprehensive information on wheat improvement research activities in all developing countries except China, Afghanistan, and Iraq.

Trends in varieties released by NARSs, 1966-90

The number of varieties released per year has risen steadily with each five-year period. By 1986-90, 65 varieties were released yearly, nearly double the number in 1966-70. More than 80% of the varieties released are spring bread wheats. The remaining 20% are divided between winter bread wheats and durum wheats (Table 20.1). These statistics are broadly congruent with the importance of each wheat type in developing country production (outside of China). Regardless of the type of wheat, more than 90% of the varieties released in developing countries in the 1980s were semidwarfs (Figure 20.1).

Origins of varieties released by NARSs

The proportion of spring bread wheat varieties originating directly from CIMMYT (i.e., based on CIMMYT crosses) or having a CIMMYT parent had risen to 84% by 1986-90 (Figure 20.2). In developing spring durum wheat varieties, CIMMYT (or CIMMYT /ICARDA) germplasm is used even more than it is for spring bread wheat (Table 20.2). The use of CIMMYT germplasm is consistently high across all regions of the developing world (Table 20.3).

More than half of the varieties released in the 1980s were derived directly from CIMMYT crosses, and another 29% of releases came from NARS crosses that used at least one CIMMYT parent. Another 12% of varieties were semidwarfs having no immediate CIMMYT parent but with CIMMYT ancestry in earlier generations. This proportion increased in the 1980s, as more NARSs began using their own varieties or breeding lines as parents in crosses. Most of the smaller national programs depend on their own crosses for less than half of their varieties. Most larger NARSs, on the other hand, depend on their own crosses to develop more than half of the varieties they release. The most popular CIMMYT crosses used in NARS breeding programs are given in Table 20.4.

Table 20.1. Frequency distribution of wheat varieties released in all developing countries, by wheat type.

Type of wheat	Number of varieties released, 1966-90	Percent of total varieties released	Percent of developing country wheat:[a]	
			Area	Production
Spring bread wheat	1,090	82.8	71	77
Spring durum wheat	126	9.6	13	9
Winter bread wheat	96	7.3	14	11
Winter durum wheat	5	0.4	2	2
Total	1,317	100.0	100	100

Source: Byerlee and Moya (1993).
[a] Excludes China.

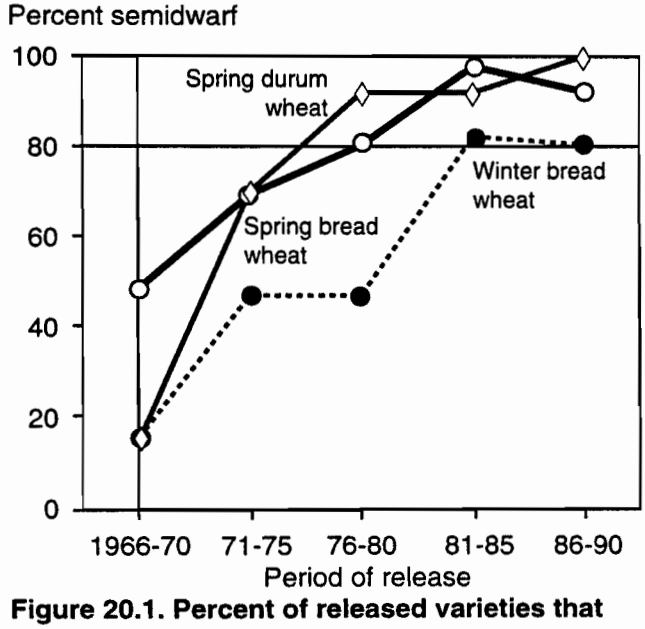


Figure 20.1. Percent of released varieties that are semidwarfs by wheat type.

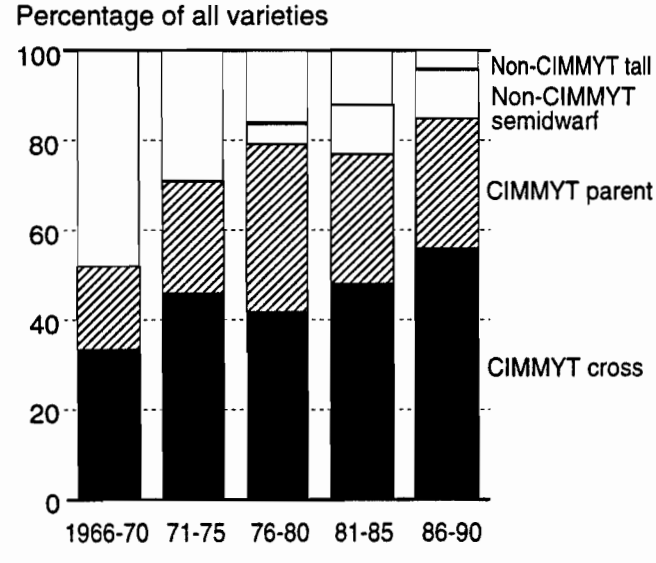


Figure 20.2. Trends in the origin of spring bread wheat varieties in developing countries, 1966-90.

Adoption of modern wheat varieties

For the purposes of this study, wheat varieties carrying semidwarfing genes are defined as "modern" varieties (MVs).[1] The adoption of MVs can be viewed as a two-stage process: Stage 1 corresponds to the first adoption of MVs to replace local or older tall varieties, and Stage 2 corresponds to the successive adoption of newer generations of MVs.

The area planted to MVs has expanded steadily since 1966. In 1969-70, semidwarf wheat occupied 12 million hectares in developing countries, or about 20% of wheat area. During the 1980s, an additional 16 million hectares were sown to MVs, so that by 1990 MVs covered close to 50 million hectares, or 70% of the wheat area in the developing world, excluding China (Table 20.5). If China, which mostly uses non-CIMMYT sources of semidwarfing genes, is included, the total area sown to MVs exceeds 70 million hectares. The continued adoption of MVs attests both to their wide adaptability and to the remarkable sustainability of the Green Revolution.

Table 20.2. Origin of spring durum wheat and winter bread wheat varieties, 1966-90.

		NARSs cross			
			No CIMMYT parent		
	CIMMYT cross[a] (%)	CIMMYT parent (%)	Semidwarf (%)	Tall (%)	All (%)
Spring durum wheat					
1966-80	64	3	2	31	100
1981-90	71	21	5	3	100
Winter bread wheat					
1966-80	0	15	23	63	100
1981-90	0	26	46	29	100

Source: Byerlee and Moya (1993).
[a] Includes varieties from the CIMMYT/ICARDA program.

Table 20.3. Origin of spring bread wheat varieties, by developing country region, 1966-90.

		NARSs cross			
			No CIMMYT parent		
	CIMMYT cross[a] (%)	CIMMYT parent (%)	Semidwarf (%)	Tall (%)	All (%)
Sub-Saharan Africa	40	31	2	28	100
West Asia/North Africa	59	21	13	7	100
Asia	40	38	11	12	100
Latin America	47	23	4	26	100
All	**45**	**28**	**7**	**20**	**100**

Source: Byerlee and Moya (1993).
[a] Includes varieties from the CIMMYT/ICARDA program.

1 The term "modern" varieties, rather than "high-yielding" varieties, is used here, since in some cases semidwarf varieties do not necessarily provide higher yields.

Table 20.4. Popular CIMMYT crosses, and lag time between release of varieties from each cross in Mexico and in other countries.

Line/cross	Total number of varieties released from cross by 1990	Year cross made in Mexico	Year of release in Mexico	Average year of release in NARSs	Average years from cross to release
Veery[a]	43	1974	1981	1986	12
Bluebird	23	1965	1970	1976	11
II8156[b]	20	1957	1966	1971	14
Pavon	14	1970	1976	1982	12
Bobwhite[a]	12	1974	1982[c]	1986	12
INIA-66	12	1961	1966	1972	11
Bittern (durum)	10	1970	1979	1985	15
Anahuac	9	1968	1973	1978	10
Sonalika[b]	9	1961	1967[c]	1975	14
Stork (durum)	9	1969	1975	1981	12
Bluejay	8	1970	1976	1982	12
Ciano-67	8	1962	1967	1975	13
Cisne (durum)	8	1967	1971	1975	13
Buckbuck	7	1973	1979	1985	12
Albatross (durum)	6	1963	1969	1974	11

Source: Byerlee and Moya (1993).
[a] Spring x winter wheat cross.
[b] Base for most important Green Revolution varieties.
[c] Not released in Mexico. In this case Mexico was not the first country releasing the variety; Sonalika was first released in India, Bobwhite in Pakistan.

Table 20.5. Area sown to different wheat types in 1990, classified by the origin of the germplasm.

		NARSs cross			
			No CIMMYT parent		
Wheat type	CIMMYT cross (%)	CIMMYT parent (%)	Semidwarf (%)	Tall (%)	All (%)
			(million ha)		
Spring bread wheat	21.8	13.8	8.5	8.1	52.2
Spring durum wheat	2.8	0.3	0.1	2.8	6.1
Winter bread wheat	0.0	0.9	0.7	9.1	10.9
Winter durum wheat	0.0	0.0	0.2	0.9	1.1
All	**24.7**	**15.1**	**9.4**	**20.9**	**70.0**
		49.2[a]			

Source: Byerlee and Moya (1993).
[a] An additional 0.5 million ha in Heilongjiang and Jiangsu Provinces of China are sown to varieties of direct CIMMYT parentage. Thus the total area planted to semidwarf wheats from CIMMYT crosses and to varieties with CIMMYT lines as parents is just over 40 million ha.

Overall, varieties originating directly from CIMMYT crosses or from NARS crosses using a CIMMYT parent now occupy 40 million hectares of wheat in the developing world. In industrialized countries, at least another 20-25 million hectares of wheat are planted to varieties with CIMMYT ancestry. Spring bread wheat varieties have been the most successful; MVs occupy an estimated 85% of spring bread

wheat area (Table 20.6) and account for 93% of production. Since spring bread wheat dominates developing country wheat production (about 70% of the total), success in spring bread wheats accounts for the overall large area sown to semidwarfs. Within regions, adoption of semidwarf spring bread wheats is lowest in sub-Saharan Africa and in WANA. The area sown to varieties derived from popular CIMMYT spring wheat crosses is given in Table 20.7.

Table 20.6. Percentage of wheat area sown to different wheat types in 1990, classified by the origin of the germplasm.

		NARSs cross			
			No CIMMYT parent		
Wheat type	**CIMMYT cross (%)**	**CIMMYT parent (%)**	**Semidwarf (%)**	**Tall (%)**	**All (%)**
Spring bread wheat	42	26	17	15	100
Spring durum wheat	47	5	1	46	100
Winter bread wheat	0	9	6	85	100
Winter durum wheat	0	0	14	86	100
All	**35**	**21**	**14**	**30**	**100**
		70			

Source: Byerlee and Moya (1993).

Table 20.7. Area sown to varieties derived from popular CIMMYT spring wheat crosses, 1990.

Cross	**Average year varieties from cross released**	**Area (000 ha)**	**Main country/ region of release**
Released before 1980			
Sonalika[a]	1969	6,290	South Asia
II8156	1967	1,140	India, Algeria
Bluebird	1978	940	Saudi Arabia, Egypt
Marcos Juárez[b]	1971	860	Argentina
Anahuac	1978	800	Brazil, Paraguay
Cisne (durum)	1975	670	Morocco, Turkey
Other (31 crosses)	..	4,160	..
Subtotal		**14,870**	
Released since 1980			
Veery	1982	3,390	Pakistan, Turkey, Iran, Chile, Mexico
Bittern (durum)	1983	920	Morocco, Turkey, Tunisia
Frigate (durum)[c]	1984	560	Syria, Algeria
Other (89 crosses)	..	4,940	..
Subtotal		**9,810**	
Total		**24,680**	

Source: Byerlee and Moya (1993).
[a] CIMMYT/India.
[b] CIMMYT/Argentina.
[c] CIMMYT/ICARDA.

Semidwarf durum wheats became available in the early 1970s, and now over half of the spring durum wheat area is sown to MVs. International breeding efforts focused on winter wheat only since 1986, and MVs of winter wheat still cover a small area.

A considerable share of spring bread wheat is produced in the temperate irrigated areas that CIMMYT classifies as Mega-environment 1 (ME 1). Much of ME1 is located in South Asia, where practically all irrigated wheat area (more than 29 million hectares) was sown to semidwarfs in 1990. In these areas, farmers have replaced the original Green Revolution varieties at least once, and usually twice, since they first adopted semidwarf wheats. Varietal replacement has enabled farmers to continue to gain from wheat breeding by taking advantage of newer varieties' higher yields and disease resistance.

During the period from 1977 to 1990, most of the increase in area of MVs occurred in rainfed areas in contrast to the Green Revolution period, which was spearheaded by adoption of MVs in irrigated areas. Adoption has followed a general pattern, in which varieties move from higher rainfall, temperate areas into more marginal, drier (and often colder or hotter) areas. These areas are often dominated by winter bread wheats or durum wheats. However, adoption MVs in rainfed areas with acid soils was particularly rapid in the 1980s.

The benefits of adopting improved wheat varieties

Genetic gains in yield — Table 20.8 summarizes available data on genetic gains in yield resulting from the successive adoption of new wheat varieties. The most complete data on genetic gains in yield resulting from the successive release of new wheat varieties come from the irrigated spring bread wheat areas of developing countries. Newer semidwarfs have continued to increase yield potential by about 0.8-1.0% annually in irrigated areas. In the 20 years since the first widely successful MVs were released, wheat breeders have raised yield potential in irrigated areas by almost 20%. Less information is available on genetic gains in yield for rainfed areas, although available data suggest that they are more modest. The most rapid progress in genetic gains in yield in the 1980s has been achieved in Brazil's acid soil areas.

Improved disease resistance — Aside from raising yield potential, wheat breeding may contribute to higher yields by reducing yield losses to diseases. One or more of the rust diseases are the most economically important diseases in most wheat production environments. The proportion of materials with superior resistance to the rusts has grown steadily. Progress has also been made in incorporating resistance to other diseases in MVs, including septoria diseases, leaf blight, and yellow leaf blotch/tan spot.

Maintenance of disease resistance — Maintaining disease resistance potentially can contribute more than gains in yield potential alone to the benefits received by farmers. Probably wheat researchers' most important contribution over the past 20 years has been to develop newer varieties that maintain resistance against evolving races of the three rust pathogens. Maintenance breeding contributes slightly more than 1% of yields each year by making it possible to avoid yield losses. Many sources indicate that potential losses to leaf rust are on the order of 25-45% of yields; Figure 20.3 shows losses of at least this magnitude to leaf rust in Mexico for older varieties (the difference between yield with and without fungicide). In irrigated areas alone, avoidance of rust disease losses represents an annual contribution of about US$ 150 million.

Changes in grain quality — Improved grain quality can also add value to new wheat varieties. However no discernible improvement in quality has occurred in bread wheats although rapid progress has been achieved in durums. This issue is becoming important in developing countries that traditionally paid a fixed price to wheat producers regardless of quality but are now moving toward freer wheat marketing, which will in many cases provide premiums for improved quality.

Stability — A variety that performs well despite various biotic and abiotic stresses is considered stable and is likely to be favored by farmers who wish to avoid downside risks. Probably the best evidence of stability is the extensive adoption of MVs across a wide range of environments, including many relatively marginal environments, and the absence of disease epidemics in most countries where this germplasm has been adopted. In addition, variability of yields of wheat in developing countries has declined significantly in the post-Green Revolution period.

Table 20.8. Summary of experimental evidence on rates of genetic gain in yields of spring bread wheat owing to the release of new varieties.

Environment/location	Period	Rate of gain (%/yr)	Source
Irrigated			
Northwestern Mexico[b]	1962-75	1.1[a,b]	Fischer and Wall (1976)
	1962-81	0.9[a,b]	P. Wall (pers. comm.)
	1962-83	1.1[a,b]	Waddington et al. (1986)
	1962-85	0.6[a,b]	Ortíz-Monasterio (1990)
	1962-89	0.7[a,b]	K. Sayre (pers. comm.)
Nepal	1978-88	1.3[b]	Morris et al. (1992)
Northwestern India[b]	1966-90	0.5-1.0[b]	Jain (1993)
Pakistan[b]	1965-82	0.8[b]	Byerlee (1990)
Zimbabwe[b]	1967-85	1.0[b]	Mashiringwani (1987)
Rainfed			
Argentina	1966-89	1.9	Byerlee and Moya (1993), Appendix A
Paraguay	1972-90	1.6[a,b]	M. Kohli (pers. comm.)
Victoria, Australia	1850-1940	0.3	O'Brien (1982)
	1940-81	0.8	
New South Wales, Australia	1926-84	0.6	Antony and Brennan (1987)
	1956-84	0.9	
	1976-84	1.7	
Western Australia	1884-1982	0.4	Perry and D'Antuono (1989)
Central India	1965-90	0.0	Jain (1993)
Hot			
Sudan	1967-87	1.0	Byerlee and Moya (1993), Appendix H
Acid soils			
Rio Grande do Sul, Brazil	1976-89	3.1	Moreira (pers. comm.)
Paraná, Brazil	1969-89	2.2	Byerlee and Moya (1993), Appendix B

Source: Byerlee and Moya (1993).
[a] Treated with fungicide to protect against disease losses and usually supported by netting to eliminate the effect of lodging.
[b] Includes semidwarf varieties only.

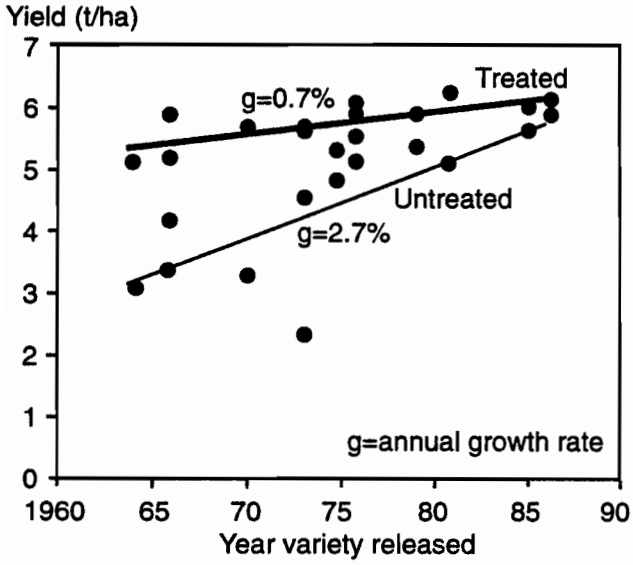


Figure 20.3. Yields of historically important varieties, with and without fungicide, Obregón, Mexico, 1990-92.
Source: K, Sayre (pers. comm.). Data for normal planting date in 1990-91 and 1991-92.

Maturity — Most of the first semidwarf varieties matured earlier than the tall varieties they replaced. Their earlier maturity was a catalyst for increasing cropping intensity, especially in South Asia. There is no evidence that changes in maturity in more recent releases have had any significant impact on cropping intensity.

The returns to international wheat breeding research

Estimating the economic benefits of an international breeding program is necessarily a crude process, given the diversity of environments and number of countries and research programs involved and thus the difficulty of estimating many key parameters. Nonetheless, a rough estimate was made of the economic contribution of the new varieties of spring wheat in developing countries in the post-Green Revolution period, 1977-90 (Table 20.9).

Table 20.9. Estimated effects of spring wheat breeding research on production by region, 1977-90.

	Sub-Saharan Africa	West Asia/ North Africa[a]	South Asia	Latin America	All
Total production increase by 1990 (million t)	0.15	2.45	9.34	3.40	15.34
Percent production increase due to Stage 1 adoption	57	43	17	53	29
Average wheat price ($1990/t)	210	210	195	195	198
Total value of production increase in 1990 (US$ 1990 millions)[a]	31	515	1,822	662	3,030
Percent germplasm of CIMMYT origin[b]	39	52	44	60	49
Value of production increase attributed to CIMMYT (US$ 1990 millions)[b]	12	268	802	397	1,485

[a] Excludes winter/facultative wheats.
[b] Varieties released since 1972 are weighted as follows: CIMMYT cross, 0.85; NARSs cross with CIMMYT parent, 0.50.

The bottom line is that the adoption of MVs of spring bread wheat over 1977-90 resulted in about 15.5 million tons of additional wheat production in 1990, valued at about US$ 3 billion. For the spring wheat areas under consideration, this amounts to a production increase of 16% (an increase of about 1.1% annually over the period).

The investment in wheat breeding by CIMMYT and NARSs was also calculated. Costs were based on estimates of research expenditures by NARSs and CIMMYT. In total some US$ 100 million per year is invested in wheat improvement research. The estimated internal rate of return in investment in wheat improvement was calculated at 50-60%. This figure is high compared with the rates of return of the order of 20-40% often calculated for crop research programs.

These rough calculations show that the momentum of the Green Revolution has been maintained, at least with respect to wheat research. The average annual increment in benefits of US$ 235 million (undiscounted) for 1977-90 is comparable to the annual increment in benefits calculated for 1966-73 of US$ 260 million (in 1990 constant prices). In the Green Revolution period, all benefits resulted from Stage 1 adoption. In the post-Green Revolution period analyzed here, Stage 2 adoption makes the major contribution to benefits.

A crude measure of CIMMYT's contribution was estimated as well based on the origin of varieties grown in the 1990s. The internal rate of return to CIMMYT's investment was calculated at 56%.

Looking to the future, it is clear that further gains in spring wheat areas will result largely from Stage 2 replacement of current MVs by newer MVs. Projecting our calculations to the future and assuming no Stage 1 benefits, the rate of return on global investment in wheat breeding falls to 43%. Since the rate of genetic gains in spring bread wheat yields may have slowed in the 1980s, the projections were also made with only half of the rate of yield gain used above. In that case the future rate of return falls to 32%.

Who gains from wheat research?

Although the distribution of benefits of research is best examined at the country level rather than at the global level, a few observations can be made about the distribution of more recent advances in wheat research at the global level.

Recent evidence confirms the results of hundreds of previous studies that small farmers have widely adopted MVs, including millions of very small farmers in South Asia, many of whom have less than one hectare of land. Another important aspect of the distribution of benefits is interregional differences in adoption of MVs. In the case of wheat research, the largest share of benefits (70%) has been received in irrigated areas, which have the greatest concentration of poor people in wheat producing areas. About half of the world's population living in poverty is located in the large irrigated tracts of South Asia alone. Nevertheless, several marginal areas, where the incidence of poverty is high, have yet to share in the benefits of wheat research, due to factors such as severe drought, soil problems, or poor infrastructure which impair adoption of MVs. New varieties can play a role in these areas, but it is likely that the greatest gains will result from improved crop and resource management, especially measures to conserve and utilize moisture in marginal rainfed areas.

Often poor consumers benefit most from research on a staple food crop such as wheat, since increased productivity leads to lower food prices. In large economies close to self-sufficiency in wheat, there is evidence that this has occurred. It is also important to remember that a large number of small-scale farmers actually buy more wheat than they sell. This group includes many smallholders in favored areas, as well as many farmers in marginal areas. In this way farmers, particularly those in marginal areas, have captured some of the benefits of technological change in favored areas.

Conclusions

Three main conclusions emerge from this study. First, the adoption of modern wheat varieties has maintained its momentum in the post-Green Revolution period. Second, CIMMYT germplasm continues to be used extensively as source material for the varieties that have diffused in the post-Green Revolution period. Third, investment in international wheat breeding research has continued to provide high rates of return.

The results of this study raise two issues that must be addressed by CIMMYT and NARSs. First, there is probably no crop in history where germplasm from one source, in this case CIMMYT, has been so widely used. This places a special responsibility on CIMMYT and NARSs breeders to use every means possible to maintain and widen genetic diversity. This effort is reflected in the use of germplasm from an increasingly wide range of sources (including wild relatives) in CIMMYT's wheat breeding program. As a wider range of materials becomes available, NARSs are releasing more varieties from different crosses, thereby increasing diversity.

Finally, the question arises of whether the spectacular gains achieved in the recent past can be maintained in the future. Opportunities to expand the area under MVs remain, especially in the more favorable winter wheat areas that began to receive attention in the 1980s. However, the expansion of MVs into more marginal areas will surely be slow and the impacts modest. In favored areas, the major source of growth will be genetic yield gains in areas already sown to MVs. It will be important to monitor progress in yield potential closely and to seek new techniques, such as through molecular biology, for increasing the efficiency of breeding. The gains in developing resistance to major diseases, especially leaf rust, and breakthroughs in other more localized diseases will make important contributions to yield stability in the years ahead, as well as free resources to work on increasing yield potential and grain quality.

Part II. Investment in and Efficiency Issues in International Wheat Breeding Research

The fact that similar agroclimatic environments, while geographically scattered, can be aggregated at the global level into relatively homogeneous agroclimatic zones (mega-environments) suggests that there might be significant economies of size in international wheat improvement research. In addition, the wheat impact study indicated that the direct use of CIMMYT products (that is, varieties derived from CIMMYT crosses) is increasing. This finding was unexpected, for the development of local breeding programs over the past 25 years should have allowed them to have a comparative advantage in developing varieties tailored to local conditions. In other words, local programs would use CIMMYT products indirectly as intermediate products or parents in their own breeding programs.

In addition, the growth in resources for international and national research slowed in the 1980s, and in many cases real resource investments in agricultural research declined sharply. It seems clear that increasing efficiency in agricultural research systems will be a driving force of the 1990s and beyond, in both developing and industrialized countries. Moreover, the hypothesis that IARCs might have a comparative advantage in developing finished products is contrary to the pressure from the TAC for IARCs to move upstream.

Against this background, a series of studies was undertaken with the following objectives:

- To document the resources invested in crop improvement research by NARSs.
- To provide quantitative estimates of the level of spillovers (measured by the relative performance of a variety developed in one location in a different location) across mega-environments, both for germplasm developed by NARSs and by CIMMYT.
- To develop a model to estimate the minimum threshold size of a production environment to justify investment in different types of wheat improvement programs of increasing complexity and with different levels of spillins.
- To estimate efficiency measures for international and national crop improvement research which would indicate the presence or absence of economies of size in crop improvement.
- To provide policy guidelines for future investment in crop improvement research at the national and international levels.

Methods

- A survey of nearly 100 wheat research programs in about 50 countries (both developing and industrialized) to estimate resources invested in wheat improvement and to obtain information on the type of crop improvement program, mandate area, composition of varietal releases, and so forth.
- Analysis of CIMMYT ISWYN data to obtain quantitative estimates of spillin parameters (Maredia et al. 1993).
- Development of a cost-benefit model of a wheat improvement program that explicitly allows for spillins (Brennan 1992; Maredia et al. 1994).
- Application of the cost-benefit model to categorize the efficiency level of the wheat research programs surveyed.
- Development of measures for comparing the efficiency of CIMMYT and NARSs and NARSs of different sizes.

Results

- The NARSs devote substantial resources to wheat improvement research. Developing country wheat research programs are generally larger than comparable programs in industrialized countries, as measured in numbers of full-time equivalent (FTE) scientists and dollars invested.
- Because the mandate production area is smaller in developing countries, the intensity of investment in NARSs (i.e., scientists or investment per million tons of wheat) is generally higher than in industrialized countries (Table 20.10). This is especially true for many smaller NARSs. Asia, where most of the large NARSs are located, is the only region where the intensity of wheat improvement research is comparable to that of industrialized countries.
- The mega-environment (ME) classification appears to be a useful way of aggregating environments over countries, as demonstrated by the performance of varieties of different ME origins across MEs. However, varieties derived directly from CIMMYT crosses outperform varieties from NARS crosses

Table 20.10. Country-level expenditures on wheat, by region.

	No. of countries	No. of scientists in wheat improvement	Avg. no. of scientists in wheat improvement per country	Total wheat production (million t)	No. of scientists per million tons of wheat produced	Total research expenditures (million 1990 US$ PPP)	Research cost per ton of wheat (1990 US$ PPP)
Sub-Saharan Africa	6	27	4	2	14.3	3	1.62
W.Asia/N.Africa	9	283	31	39	7.2	38	0.95
Asia	5	710	142	162	4.4	41	0.25
Latin America	11	123	11	20	6.0	14	0.71
All developing countries	**31**	**1,142**	**37**	**224**	**5.1 (30.5)[a]**	**96**	**0.43 (3.15)[a]**
Australia	1	72	72	14	5.3	6	0.43
USA	1	278	278	60	4.6	44	0.73

Source: Bohn and Byerlee (1993).
[a] Unweighted averages.

in most MEs, especially in irrigated and high rainfall MEs, which make up a large proportion of developing country wheat production (Table 20.11). Thus the potential for spillins from other NARSs and especially from CIMMYT is large in most environments.

- The above information was combined in an economic framework to compute the threshold size of a mandate area to justify investment in a full wheat breeding program Using program-specific values for resources invested in wheat improvement, over 40% of wheat breeding programs are found to be inefficient (that is, a smaller program that tests imported materials would give a higher rate of return on the investment), and many are likely to be uneconomic at current levels of investment (that is, they have a negative rate of return) (Table 20.12). These inefficiencies relate both to small mandate areas (the small country problem, or a small region within a country) and to the relatively large number of scientists employed in many programs. They also reflect the high level of potential spillins.
- Various efficiency indicators in Table 20.13 suggest that CIMMYT is a relatively low cost producer of improved germplasm. In general CIMMYT costs are lower than the NARSs average on all indicators and in all regions, except in the large NARSs, all of which are in Asia. Although the cost per scientist is high in CIMMYT, the technical efficiency in terms of number of crosses made and number of varieties produced per scientist more than compensates for this high cost.
- The differences in costs per hectare sown to varieties released since the 1980s for programs of different sizes, confirm the large apparent economies of size in wheat improvement research (Table 20.14).
- The costs borne by CIMMYT are only a part of the total cost of developing and releasing improved varieties based on CIMMYT crosses. In particular, NARSs pay a large share of the costs of the international nurseries, and pay all of the cost of screening and testing varieties based on CIMMYT crosses for release in their countries. In total, it is estimated that NARSs spend $US1 in testing and releasing varieties based on CIMMYT crosses for every dollar spent by CIMMYT. This vividly demonstrates that the international system is a truly collaborative system with strong participation by NARSs in terms of contribution of resources to the international testing system.

Table 20.11. Relative yield performance of spring wheat cultivars of different origins in various mega-environments, 1980-89.

Mega-environment of variety origin	Relative yield in mega-environment where tested[a]						
	1 Irrigated	2 High rainfall	3 Acid soils	4A Winter drought	4B Early drought	5A High temperature	6 High latitude
1. Irrigated	**100**	95	84	90	88	102	94
2. High rainfall	95	**100**	81	92	90	89	96
3. Acid soils	89	96	**100**	85	90	98	100
4A. Winter drought	99	94	78	**100**	83	91	93
4B. Early drought	90	97	89	91	**100**	90	99
5A. High temperature	88	86	92	82	89	**100**	92
6. High latitude	88	89	84	87	91	84	**100**
CIMMYT/Mexico	111	113	99	101	101	101	98

Source: Maredia (1993). Based on an analysis of ISWYN data.
[a] Yield expressed relative to the yield of cultivars originating in that mega-environment (= 100).
[b] Cultivars derived from CIMMYT crosses and released in Mexico.

Table 20.12. Wheat research programs in developing countries, classified by the NPV decision criterion for two levels of spillins

Group	Result of the analysis	Interpretation	Region	Assumed level of research spillins (% yield advantage of locally developed varieties) 6%	2%
				Number of research programs	
I	NPV < 0	Cannot justify current level of investment in wheat research (testing or breeding)	Sub-Saharan Africa	2	2
			W.Asia & N.Africa	4	4
			South Asia & China	0	0
			Latin America	6	6
			Total	**12**	**12**
II	0 < NPV <	Investments in breeding are earning positive NPV, but less than testin	Sub-Saharan Africa	1	5
			W.Asia & N.Africa	0	4
			South Asia & China	1	3
			Latin America	2	7
			Total	**4**	**19**
III	NPV > NPV of testing program	Current investments in breeding more profitable than testing	Sub-Saharan Africa	6	2
			W.Asia & N.Africa	18	14
			South Asia & China	21	19
			Latin America	10	5
			Total	**55**	**40**
			Grand total	**71**	**71**

Source: Maredia and Byerlee (1985).
a Average across all programs under 2% yield gains assumption.

- Small NARSs depend relatively more on direct introduction of technologies from the international system. However, large NARSs reap the largest absolute gains from the international system (Table 13).

Two final questions remain unanswered by these results. First, what is the optimal strategy for CIMMYT in terms of the type of products it develops? Second, how should decisions be made at the international level? If NARSs make decisions on the basis of the availability of spillins from the IARCs, then many are investing too much in a technology development (breeding) capacity. On the other hand,

Table 13. Comparative indices of efficiency of wheat improvement research programs grouped by size, 1991

	NARSs by size of wheat production (million t)						
	0-0.5	0.5-1.0	1.0-2.0	2.0-5.0	>5.0	Average or total	CIMMYT
Wheat production (million t)	.05	.29	.99	3.25	20.76	110.6	
Full-time (FTE) wheat scientists	4	5	11	37	80	673	36
No. crosses/yr	170	260	1,250	2,140	6,530	48,440	12,000
No. of varieties/yr	0.6	0.8	1.2	2.8	4.6	51.7	23.2
% varieties from own crosses	14	42	24	42	53	51	
% area from own crosses	5	18	16	49	64	57	
% research resources to own crosses	47	81	64	81	87	70	
% area from "CIMMYT varieties"	95	62	66	51	32	89	
% total area under "CIMMYT varieties"	0.6	4.1	9.3	28.1	57.9	100	
FTE/million t	92	18	11	11	4	6	
Crosses/FTE	38	52	112	57	82	72	333
Varieties/FTE	.14	.16	.11	.07	.06	.08	.64
Ha/variety	14	111	201	325	951	478	450

Source: Byerlee (1994).

Table 14. Comparative indices of cost of varietal development for wheat research programs grouped by size, 1991

	NARSs by size of wheat production (million t)					
	0-0.5	0.5-1.0	1.0-2.0	2.0-5.0	>5.0	Average or total
Cost/ variety (US$ PPP[a])						
NARS crosses	1380	1620	2210	2620	2080	2,200
CIMMYT crosses*	430	620	990	840	430	650
CIMMYT/NARS**	445	802	1302	830	1130	1,026
Cost/ha sown (US$ PPP[a])						
NARS crosses	270.1	34.1	15.0	6.9	1.8	3.3
CIMMYT crosses*	27.8	5.2	5.0	2.9	0.7	2.1
CIMMYT/NARS**	28.9	6.1	5.9	3.8	1.5	2.9
Cost/ha sown (US$ OER[b])						
NARS crosses	30.0	15.6	3.2	3.2	0.4	1.1
CIMMYT crosses*	5.4	2.9	1.2	1.2	0.1	0.7
CIMMYT/NARS**	6.3	3.8	2.1	2.1	1.7	1.6

Source: Byerlee (1994)
* Includes only cost of NARS testing and release.
** Includes CIMMYT costs as well as NARS costs of testing and release for varieties based on CIMMYT crosses.
[a] Purchasing power parity exchange rate.
[b] Official exchange rate.

if IARCs make decisions taking NARS technology development capacity as fixed, then IARCs (constrained by limited resources) may be investing too much in applied research versus strategic research that would have an even higher payoff. The present work requires extension to look at the optimal division of labor under different resource scenarios.

Implicatiions

The results described above suggest the following:

- CIMMYT must be cautious in moving upstream and toward the production of intermediate products at the expense of relatively finished products. There appears to be considerable demand for CIMMYT's finished products, especially by small NARSs but also by some large NARSs with large irrigated and rainfed wheat producing areas.
- NARSs, especially small NARSs and programs serving small environments in larger NARSs, must rationalize investment in wheat improvement research. There appears to be substantial scope to consolidate the number and size of wheat breeding programs in NARSs and to organize regional and international networks to divide research responsibilities and share products.

Donors should invest in strategies that enhance the efficiency and complementarity between national and international wheat research.

References

Bohn, A., and D. Byerlee. 1993. The wheat breeding industry in developing countries: An analysis of investments and impacts. Part I of the 1992-93 CIMMYT World Wheat Facts and Trends. Singapore: CIMMYT.

Brennan, J.P. 1992. Economic Criteria for Establishing Plant Breeding Programs. CIMMYT Economics Working Paper 92-01. Mexico, D.F.: CIMMYT.

Byerlee, D. 1994. On the comparative advantage of international agricultural research: Exploiting economies of size to generate global spillovers. Paper presented at the workshop, "Integration of Research Efforts of ICRISAT with NARSs with other International Research Institutions," ICRISAT, Hyderabad, India, 14-16 December.

Byerlee, D., and P. Moya. 1993. Impacts of International Wheat Breeding Research in the Developing World, 1966-1990. Mexico, D.F.: CIMMYT.

Englander, A.S. 1991. International technology transfer and agricultural productivity. In R.E. Evenson and C.E. Pray, eds., Research and Productivity in Asian Agriculture. Ithaca, New York: Cornell University Press. Pp. 291-313.

Maredia, M. 1993. The Economic of the International Transfer of Wheat Varieties. PhD dissertation. East Lansing, Michigan: Department of Agricultural Economics, Michigan State University.

Maredia, M.K., and D. Byerlee, 1995. Determining the efficiency of research in the presence of international spillovers: Wheat research in developing countries. Draft paper. East Lansing, Michigan: Department of Agricultural Economics, Michigan State University.

Chapter 21.

Disciplinary Research in the Wheat Program

Gene P. Hettel

In addition to the mainline breeding programs, various disciplines play important roles in the overall effort.

Wheat Germplasm Bank

The Germplasm Bank supports wheat improvement by maintaining collections of selected germplasm representative of all significant germplasm pools. Within the CGIAR, CIMMYT has responsibility for base collections of bread wheat and triticale, as well as back-up collections of spring durum wheat and wheat's wild relatives. Base collections of these two groups are maintained by the International Center for Agricultural Research in the Dry Areas (ICARDA). All these collections provide a reservoir of characters needed now and in the future to face the ever-changing requirements of plant breeding.

Major activities

The Bank supports active breeding programs by assembling, characterizing, evaluating, and documenting wheat varieties, wild relatives, and genetic stocks. These materials, more than 100,000 accessions acquired over 50 years of breeding activities in Mexico, are available to bonafide scientific programs. Priority is given to national programs in developing countries. About 15,000 samples are distributed annually.

The Bank conserves, evaluates, regenerates, and documents materials. Accessions are stored at -2°C, and should remain viable for up to 50 years. Longer term storage, at -18°C, should enable seed to remain viable for up to 100 years.

In conjunction with the International Plant Genetic Resources Institute (IPGRI) and gene banks of developing and developed countries, CIMMYT has, on occasion, participated in collecting materials from threatened areas and/or germplasm having unique characteristics. Since 1984, these expeditions have contributed nearly 3500 accessions to the Bank.

Other activities involve:

- Correctly identifying accessions. This is a vital element to the Bank's utility and efforts are being intensified to make sure an accession identified as a particular variety is indeed that variety.
- Inspecting all new accessions upon arrival and then, if found free of contamination, growing them in isolation. As for seed already in the Bank, studies are underway to isolate and identify microorganisms.
- Transferring traits (such as tolerances and resistances to biotic and abiotic stresses) found in Bank accessions to materials having better agronomic backgrounds, thus easing access to them and improving their utility to breeders.
- Facilitating the search for traits by providing reliable information about individual accessions. For ease of access, we are building computer databases containing this information—called passport data—and other salient characters of materials in the Bank. These databases will be readily

available to anyone involved in wheat germplasm improvement. Analysis of accession data enables breeders to identify particular materials or geographic areas that can serve as sources of useful traits.

Challenges for the future

Specific challenges of the Bank include:

- Reducing the effect of genetic drift, a consequence of natural selection and a constraint associated with seed multiplication and regeneration. To minimize this problem, seed is being regenerated only when necessary. Plans include accomplishing such regeneration only under controlled conditions in special screenhouses.
- Developing a system by which the global collection can be reduced to a more meaningful core collection without losing variability.
- Providing better communications and linkages among the germplasm banks of the world. This will be vital to future progress.

For more information on wheat genetic resources at CIMMYT, see Skovmand et al. (1992).

Wheat Wide Crosses

The Wheat Wide Crosses Laboratory adds new variability to the wheat gene pool by introducing alien genetic material through intergeneric and interspecific hybrids (Mujeeb-Kazi and Hettel 1995). The products of Wheat Wide Crosses (WWC) are passed on to the mainstream breeding programs of CIMMYT and national programs. WWC assists in various basic research projects underway at CIMMYT.

Major activities

About 40% of the projects currently underway involve expanding the wheat gene pool. Most WWC efforts in this applied area focus on two sets of material—one distantly (intergeneric) and the other closely (interspecific) related to wheat.

Distant relatives include approximately 325 annual/perennial species. Significant progress has been made in producing complex hybrids, especially in crosses of wheat with *Agropyron curvifolium, A. distichum, A. junceum, Elymus giganteus,* and several other species derivatives that require additional breeding. Advanced derivatives of these hybrids have improved resistance to leaf rust, helminthosporium, scab, and septoria; prospects are good for improving salt tolerance as well. Just recently, Pakistan released two bread wheat varieties derived from *A. distichum* hybrids: Pasban 90 for irrigated areas and saline soils and Rohtas 90 for rainfed areas. Other national programs are evaluating some progeny from this intergeneric work and CIMMYT has incorporated some in its breeding programs. Efforts involving these distant relatives are being reduced and are considered long term because the process is so complex.

More recently, WWC is incorporating traits into wheat from closely related species (mostly *Triticum* species). Just recently, material showing excellent spot blotch resistance was turned over to the bread wheat breeders for additional crossing and release of elite germplasm. This material was derived from synthetic lines of which about 525 have been created so far (Mujeeb-Kazi and Hettel 1995). All the

crosses producing the synthetics were of durum wheat by *Triticum tauschii* (Syn. *Aegilops squarrosa*), which has allowed us to tap into the genetic variability of this wild relative. Other disease resistances being sought in this material are those to head blight, septoria, and Karnal bunt. Prospects are also promising for finding good drought and salt tolerance. In the 1992-93 preliminary yield trial for favorable irrigated environments at Ciudad Obregón, a synthetic (Crocethia_1/*T. tauschii*) crossed to the bread wheat Bacanora yielded 7.7 t/ha—not only outyielding the other 838 promising lines in the trial (no. 2 yield a ton less), but surpassing its Bacanora parent by 21%.

New techniques are being exploited in WWC's second major area of effort, i.e, basic research, which aims at reducing the cost of breeding and finding more efficient ways of accomplishing the applied work. One is fixing the homozygosity of the wheat plant, required in some basic research projects, without going through several generations. Important to this work are wheat by maize or wheat by *Tripsicum* crosses that have vastly expanded our ability to produce polyhaploids, a technique first described two years ago in England. WWC has dramatically increased the number of live plants per wheat by maize or *Tripsicum* cross. This technique has played an important supporting role in mapping the wheat genome.

Other basic research efforts are aiming to develop techniques that provide more reliable and efficient ways of identifying alien genes and transferring them to wheat. For example, one is using callus culture to facilitate the transfer of alien genes from distant relatives such as *Aegilops variabilis*.

Challenges for the future

Developing and/or implementing the following techniques will facilitate future progress in WWC:

- Facilitating the transfer of alien genes to wheat and for their tracking in segregating populations.
- Using direct transformation, i.e., applying molecular techniques to transfer a gene from alien material and getting it to express its trait.
- Applying protoplast fusion and regeneration methodologies to further exploit and speed up the use of the synthetics.

Wheat Crop Protection

The objective of the wheat pathologists is to increase the stability of wheat production by reducing or eliminating the losses in yield and quality caused by diseases, insects, and other pests. The pathologists concentrate their efforts primarily on germplasm development, discipline-related research oriented to crop production, and training.

Breeding for resistance

The development of germplasm, which has stable and durable disease resistance, is facilitated by identifying resistance factors(s) and establishing screening protocols. Incorporating resistance is the responsibility of both breeders and pathologists.

All new wheat germplasm is routinely screened for resistance to the diseases of global significance. Resistant germplasm is also being developed for regionally important diseases and new emerging disease problems. Occasionally, the pathologists draw upon the expertise of CIMMYT's Seed Health Unit and Mexico's Sanidad Vegetal to address plant quarantine issues.

Variability in natural wheat populations is the basis for genetic enhancement and critical to developing stable disease resistance. The germplasm found in gene banks and alien species is the first line of defense when looking for new or different sources of resistance. The pathologists work with the Wheat Germplasm Bank and the Wide Crosses Laboratory to assess their many accessions and genetic stocks for specific disease and pest resistances. In some cases, identified sources of resistance can be used directly by the breeders, but often sources are not suitable for direct use and may require the collaborative efforts of the pathologists, the Bank, and Wide Crosses to transfer it to better agronomic backgrounds.

Discipline-related research

Through global disease surveillance and assessment, we can identify important diseases and pests in different geographical regions. This information helps define research priorities and calculate the value of resistance. As management of the three rusts improves, other diseases are now being recognized. Currently, major efforts are underway with the septoria and helminthosporium diseases, barley yellow dwarf virus (Bertschinger 1994), Karnal bunt (Fuentes and Hettel 1992), fusarium head blight (Moreno and Gilchrist 1994), bacterial diseases, soil pathogens (Dubin and Bimb 1994), and Russian wheat aphid (Robinson 1994). Most pathogen and insect species are composed of races or strains that further complicate resistance breeding efforts. Pathologists monitor these races, their capacity to change or mutate, and their global distribution.

Over the last 20 years, pronounced changes in the developing world's cropping systems, especially under irrigation, have caused an evolution of different pathosystems involving numerous disease and pest complexes. Technology developments in mono-crop systems using minimum tillage practices are also evolving rapidly and corresponding pathosystems are emerging. The ability to address these complexes and their inter-related components will require much more discipline and interdisciplinary research efforts.

Training

The pathologists cooperate with the breeders in a wheat improvement training program that combines critical elements and philosophies into a core curriculum. This curriculum provides scientists from national programs with a comprehensive exposure to the factors required to develop and run a successful germplasm improvement program. This is followed by more specialized training in either breeding or crop protection.

Challenges for the future

As mentioned earlier, sources of resistance from related or distant wheat relatives—especially through recent development of the synthetic hexaploids—are proving to be of great value. This line of research needs to be reinforced as developments in wide crosses and biotechnology bring more exotic material to the stage of availability to breeders. The pathologists will need to develop better protocols for the priority diseases if the increase in available alien infusions are to be properly utilized.

For more details on Wheat Crop Protection, see Saari and Hettel (1993).

Crop Management and Physiology

These two areas of research provide strategies on achieving increases in yield potential and yield under stress (e.g., drought, cold, heat, salinity), as well as examining interaction of genotypes under various agronomic practices. The agronomists and physiologists primarily serve two groups of clients: CIMMYT wheat breeders and national program researchers. In collaboration with national program researchers, technology is developed that can achieve sustainable production in major cropping systems of the developing world that involve wheat.

Major activities

The agronomists and physiologists are involved in the following efforts:

- Studying and defining the principles and diagnostics relating to the components of wheat agronomy in the major wheat mega-environments (MEs). Specific applications of these principles are left in the hands of national program agronomists. ME1, optimally irrigated wheat under temperate conditions, receives the highest priority. A recent achievement has involved determining the nitrogen use efficiency of the major genotypes for ME1.
- Unravelling the morphological and physiological traits associated with yield potential and yield in stressed environments with a goal of developing selection criteria for breeders. ME1 (Acevedo 1992) and ME5 are currently receiving special attention. Germplasm screening tools are being developed for breeders (Balota et al. 1993, Delgado et al. 1993) and agronomic practices are being examined for heat-stressed areas.
- Providing back-up for agronomic management at the experiment stations so that breeders can select germplasm for specific stress conditions.
- Testing and verifying conceptual and simulation models so that they can be used reliably in substantiating management principles and for recommending physiological traits for breeding purposes in the various MEs.
- Maintaining and improving the natural resource base in major cropping systems that involve wheat (i.e., rice-wheat in Asia, soybean-wheat in South America, cotton-wheat in certain zones of Africa, and maize-wheat in the highlands of Mexico), while achieving productivity with an efficient use of agricultural inputs. Recently, the sustainability problems of the rice-wheat rotation have been more clearly defined.
- Using on-farm research as a tool in work involving sustainability issues in the major farming systems involving wheat (e.g., rice-wheat, soybean wheat). The agronomists also conduct more traditional, adaptive on-farm research in several developing countries as part of bilateral or regional special projects.
- Training of agronomists from developing country national programs in Mexico and, in some cases, within a region (e.g., Argentina/CIMMYT partnership for Latin America). Emphasis is on the principles of growing wheat and their application to specific situations.

Challenges for the Future

Major challenges for the future in the areas of crop management and physiology include:

- Identifying the mechanisms that will enhance yield potential under optimal conditions and yield under stressed conditions, particularly drought. Progress will be slow in this area until these mechanisms are known and understood.
- Improving productivity and sustainability of the rice-wheat cropping system of South Asia. In 1994, CIMMYT joined forces with India, Bangladesh, Pakistan, and Nepal and other IARCs including IRRI, ICRISAT, and IIMI, in a 4-year initiative entitled Sustainability of Rice-Wheat Based Cropping Systems in the Indo-Gangetic Plain.

For more information on crop management and physiology research in the CIMMYT Wheat Program, see Acevedo and Hettel (1993).

References

Acevedo, E. 1992. Increasing the Yield Potential of Irrigated Bread Wheat: Basis for Physiological Research at CIMMYT. Wheat Special Report No. 12. Mexico, D.F.: CIMMYT.

Acevedo, E., and G.P. Hettel, eds. 1993. A Guide to the CIMMYT Wheat Crop Management and Physiology Subprogram. Wheat Special Report No. 16. Mexico, D.F.: CIMMYT.

Balota, M., I. Amani, M.P. Reynolds, and E. Acevedo. 1993. An Evaluation of Membrane Thermostability and Canopy Temperature Depression as Screening Traits for Heat Tolerance in Wheat. Wheat Special Report No. 20. Mexico, D.F.: CIMMYT.

Bertschinger, L. 1994. Research on Barley Yellow Dwarf: State of the Art of the CIMMYT Program and Its Future Research Focus. Wheat Special Report No. 15. Mexico, D.F.: CIMMYT.

Delgado, M.I., M.P. Reynolds, A. Larqué-Saavedra, and T. Nava. 1994. Genetic Diversity for Photosynthesis in Wheat under Heat-Stressed Field Environments and Its Relation to Productivity. Wheat Special Report No. 30. Mexico, D.F.: CIMMYT.

Dubin, H.J., and H.P. Bimb. 1994. Studies of Soilborne Diseases and Foliar Blights of Wheat at the National Wheat Research Experiment Station, Bhairahawa, Nepal. Wheat Special Report No. 36. Mexico, D.F.: CIMMYT.

Fuentes-Davila, G., and G.P. Hettel, eds. 1992. Update on Karnal Bunt Research in Mexico. Wheat Special Report No. 7a. Mexico, D.F.: CIMMYT.

Moreno, J.I., and L. Gilchrist. 1994. Fusarium Head Blight of Wheat. Wheat Special Report No. 21b Mexico, D.F.: CIMMYT.

Mujeeb-Kazi, A., and G.P. Hettel, eds. 1995. Utilizing Wild Grass Biodiversity in Wheat Improvement: 15 Years of Wide Cross Research at CIMMYT. CIMMYT Research Report No. 2. Mexico, D.F.: CIMMYT.

Robinson, J. 1994. Identification and Characterization of Resistance to the Russian Wheat Aphid in Small-Grain Cereals: Investigations at CIMMYT, 1990-92. CIMMYT Research Report No. 3. Mexico, D.F.: CIMMYT.

Saari, E.E., and G.P. Hettel, eds. 1993. A Guide to the CIMMYT Wheat Crop Protection Subprogram. Wheat Special Report No. 24. Mexico, D.F.: CIMMYT.

Skovmand, B., G. Varughese, and G.P. Hettel. 1992. Wheat Genetic Resources at CIMMYT: Their Preservation, Enrichment, and Distribution. Mexico, D.F.: CIMMYT.

Appendix 1. Bread wheat, durum wheat, and triticale varieties derived from CIMMYT germplasm released during the 1989-94 period.

NAME	ABR	PEDIGREE / SELECTION HISTORY	YEAR	COUNTRY
Bread Wheat				
AGUA DULCE CIAT	ADUL	CHEEL CM40038-6M-4Y-2M-1Y-2M-1Y-0B-0BOL	1989	BOLIVIA
AMAZONAS	AMAZ	PF70354/BOW CM67910-7Y-1M-8Y-1M-2Y-0M-1ELV-0ELV-0PRT	1993	PORTUGAL
ANDINO-INIA	ANDINO	MON/IMU CM61942-4Y-2M-2Y-2M-2Y-OM-0PER	1992	PERU
ANDRY 91	ANDRY	PF7339/ALDAN CM59172-0MDG	1991	MADAGASCAR
ANMOL 91	ANMOL	KVZ/TRM//PTM/ANA CM43903-H-4Y-1M-1Y-3M-3Y-0B	1991	PAKISTAN
ANNAPURNA 4	ANNA4	KVZ/3/CC/INIA//CON//EL GAU/4/SON64	1994	NEPAL
ARANDAS F90	ARA90	TUI CM74849-2M-2Y-3M-2Y-0B-0MEX	1990	MEXICO
ARIANA-94	ARI94	BOW/NAC//VEE/3/BJY/COC CM92088-J-0Y-0M-0Y-4M-0Y-0AFG	1994	AFGHANISTAN
ARIVECHE M93	ARIV93	LUAN CM100587-E-0M-0Y-030M-8Y-1Y-0M-0MEX	1993	MEXICO
BALAN 91	BALAN	KVZ/CGN	1991	GUATEMALA
BARANI 83	BAN83	BB/GALLO/3/GTO/7C//BB/CNO CM32347	1990	PAKISTAN
BAVIACORA M93	BAV93	BABAX CM92066-J-0Y-0M-0Y-4M-0Y-0MEX	1993	MEXICO
BHRIKUTI	BHRI	CONT/COC75/3/PLO//FURY/ANA75	1994	NEPAL
BL 1135	BL1135	QTZ/TAN	1994	NEPAL
BOHOUTH 6	BOHO6	CROW CM40457-0SYR	1991	SYRIA
BR 33-GUARA	BR33	BUC/BJY CM49641-9Y-1M-4Y-0Y-BRA	1989	MEXICO
BR 40-TUIUCA	BR40	ANAHUAC/HUACAMAYO CM49258-2Y-2M-3Y-0Y-0BRA	1991	BRAZIL
BUCK BAGUAL	BBAG	KVZ/JAR SWM1296	1989	ARGENTINA
BUCK GUARANI	-	URES/JUNCO CM73820	1993	ARGENTINA
CARRIZO T89	CAZO	HAVIK CMH80A.383-1B-1Y-1B-1Y-1B-1Y-0B-0MEX	1989	MEXICO
CHAM 4	CHAM4	FLK/HORK CM39816-1S-1AP-0AP-0LBN	1989	LEBANON

APPENDIX 1. CONTINUED.

NAME	ABR	PEDIGREE / SELECTION HISTORY	YEAR	COUNTRY
Bread Wheat				
CHAM 6	CHAM6	NESSER CM39992-8M-7Y-0M-0AP-0LBN	1991	LEBANON
CHAM 6	CHAM6	NESSER CM39992-8M-7Y-0M-0AP-0SYR	1991	SYRIA
COOPERACION CALQUIN	COCAL	BOBWHITE CM33203-H-8M-8Y-1M-1Y-1M-0Y-0ARG	1989	ARGENTINA
CPAN 3004	CP3004	GIL/AUST 11-61.157//CNO/NO/VEE	1989	INDIA
CULIACAN T89	CULIACAN	TUI CM74849-2M-2Y-3M-2Y-0B-46M-0Y-0MEX	1989	MEXICO
CUTLER	CUTLER	CNO/SN64//Y50E5/GABATO/3/INIA F2 SELECTION	1991	CANADA
DEKA	DEKA	VEE//GOV/MUS	1992	ZIMBABWE
DUMA	-	AU/UP301//GLL/SX/3/PEW/4/MAI/MAYA//... CM67245-C-1M-3Y-1M-6Y-1M-0Y	1993	KENYA
EL NIELAIN	ELN	CMH72A.390-0SDN	1992	SUDAN
ESTANZUELA BENTEVEO	EBEN	BOBWHITE CM33203-K-10M-7Y-3M-2Y-1M-0Y-0URY	1989	URUGUAY
ESTANZUELA COLIBRI	ECOL	BAGULA CM59123-4M-1Y-1M-5Y-3M-0Y-0URY	1991	URUGUAY
ESTANZUELA PELON 90,	EPEL	KVZ/TRM SWM3879-9Y-13M-3Y-1M-0Y-0URY	1990	URUGUAY
FALAT	FALAT	VEERY #5 CM33027-F-15M-500Y-0M-87B-0Y-IRN	1990	IRAN
FALY 92	FALY	MUNIA CM75748-F-1M-2Y-04M-7Y-1B-0Y-0MDG	1992	MADAGASCAR
GEMMIZA 1	GMZ1	MAYA74/ON//1160.147/3/BB/GALL/4/CHAT CM58924-1GM-0GM-0EGY	1991	EGYPT
GENE	GENE	CLEO/PCH//ZZ SMW777426*-OUSA	1992	USA
GIZA 165	GZ165	CNO/MFD//MON CM43339-C-1Y-1M-2Y-1M-1Y-0B-0EGY	1991	EGYPT
GRANERO INTA	GRAI	BUC/BJY CM49641	1989	ARGENTINA
GRANIVO TUC	GTUC	TODY CM67394-11Y-1M-2Y-1M-3Y-0B-0ARG	1989	ARGENTINA
GUAMUCHIL M93	GUAM93	CATBIRD CM91045-6Y-0M-0Y-1M-9Y-0B-0MEX	1993	MEXICO
GUAPAY CIAT	GUAT	KEA CM21335-C-9Y-3M-1Y-1Y-1Y-0B-0BOL	1990	BOLIVIA

APPENDIX 1. CONTINUED.

NAME	ABR	PEDIGREE / SELECTION HISTORY	YEAR	COUNTRY
Bread Wheat				
HAIDER-94	HAID94	AU/UP301//GLL/SX/3/PEW/4/MAI/MAYA//... CM67245-C-2M-0Y-0PAK	1993	PAKISTAN
HAR1685		ND/VG9144//KAL/BB/3/YACO/4/VEE4 CM85836-50Y-0M-0Y-3M-0Y-0ETH	1994	ETHIOPIA
HOFF	HOFF	PROBSTORFER EXTREM/TOB66 SWM730865*-6H-2P-1H-0	1992	USA
HP1731	HP1731	LIRA//PRL/TONI	1994	INDIA
HS 207	HS207	VEERY CM33027-0HS-0IND	1989	INDIA
HS 240	HS240	BOW/PVN	1989	INDIA
IAC 161-TAIAMA	IAC161	KVZ-GV-TITO CM30817-C-10Y-2M-1Y-0M-0BRA	1989	BRAZIL
IAC 289-MARRUA	IAC289	VEERY CM33027	1992	BRAZIL
IAPAR 32-GUARATA	IA32	ALDAN/IAS58 CM53481-14Y-1G-0G-1G-0G-0BRA	1989	BRAZIL
IAPAR 34-GUARAGI	IA34	ALD/PAT7219 CIMMYT CROSS	1989	BRAZIL
IAPAR 42-IBIARA	IA42	CEP7779//MRS/COC CM70411-0L-2G-29G-0G	1990	BRAZIL
IAPAR 47	IA47	CHAT CM33090-M-4M-2Y-4M-0Y-0BRA	1991	BRAZIL
ICA TENZA	ICTZ	MONCHO/IMURIS T 79 CM61942-4Y-2M-2Y-2M-2Y-0M-0COL	1989	COLOMBIA
ICA YACUANQUER	ICYU	MRNG/4/NAD63/TOR//PCH/3/BLT/MES/5/ PAT72195*2/ ZP/CM57616-A-3Y-1Y-4M-2Y-1M-0Y-0COL	1991	COLOMBIA
ICTA SIJA	ICSJ	MUNIA CM75748-F-1M-2Y-04M-5Y-2B-0Y-0X-0GTM	1992	GUATEMALA
INIAP COJITAMBO 92	INCO	BON/YR/3/F35.70//KAL/BB CM41860-A-5M-2Y-3M-1Y-1M-1Y-0B-0ECU	1994	ECUADOR
INIAP COTOPAVI	INCP	BUHO/4/SON64/TZPP/Y50/NP/3/LAC 617.67A E-II-75-1935-1E-9E-1E-1E-0E	1989	ECUADOR
INIAP QUILINDANA 94	INQL	PEG/PF70354/4/KAL/BB//ALD/3/MRNG CM58340-A-1Y-2Y-3M-2Y-1M-0Y-0ECU	1994	ECUADOR
KAGHAN-93	KAG93	BAGULA CM59123-3M-1Y-2M-2Y-OM-0PAK	1993	PAKISTAN
KLEIN DRAGON	KLDR	LOXIA CM64693-3M-1Y-1M-3Y-0M-K310-OARG	1992	ARGENTINA
KOHSAR-92	KOH92	PSN/BOW CM69-1M-1Y-1M-2Y-0M-0PAK	1993	PAKISTAN

APPENDIX 1. CONTINUED.

NAME	ABR	PEDIGREE / SELECTION HISTORY	YEAR	COUNTRY
Bread Wheat				
KWARE	KWARE	BB/GALLO//CJ71/T.AESTIVUM//KAL/BB CM34555-B-1M-4Y-1M-2M-0Y-0TZA	1989	TANZANIA
LAZA 92	LAZA	LOV23/BJY/3/BB/NOR//CNO/7C/4/MON/ALD CM88375-15MY-0M-0Y-2M-0Y-0MDG	1992	MADAGASCAR
LIRA SA 92	LIRA92	LIRA CM43903-0TUR	1992	TURKEY
LOMAX TUC	LTUC	WRM//KAL/BB/3/BOW CM69828-2T-3Y-02M-2Y-0B-0ARG	1989	ARGENTINA
MANAMBINA 92	MNBN	ALD/CEP75630//CEP75234/PAT7219/3/PHO/FCT CM92017-K-0Y-0M-0Y-3M-0Y-0MDG	1992	MADAGASCAR
MANGALA	MANG	GLL/AUST61.157//CNO/NO66/3/KAL/BB	1989	INDIA
MARICO	MARICO	BROADBILL CM43381	1993	S. AFRICA
MBEGA	-	FINK	1993	KENYA
MRNG-ALDAN	-	MRNG/ALDAN CM46961-13M-1Y-2M-601Y-3PTZ-0Y-0BDI	1990	BURUNDI
NATA	NATA	VEERY CM33027	1989	ZIMBABWE
NESSER	NESSER	NESSER CM39992-8M-7T-0M-0AP-0JOR	1990	JORDAN
NGAMIA	-	BUC CM31678-R-4Y-2M-1Y-2M-1Y-08	1993	KENYA
NINGMAI 7	NING7	SHANGHAI #4	1993	CHINA
NIRY 92	NIRY	BUC/BJY//CEP80120 CM88156-5M-0Y-0N-7Y-0M-0MDG	1992	MADAGASCAR
NKWAZI	-	KVZ/3/TOB/CTFN//BB/4/BLO/5/VEE#5/6/...		
OCEPAR 16	OCEP16	BNQ/CNT10/6/PJ//CNO/7C/4/CNO/INIA//BB/ 3/PCI/5/B1 CM58331-0P-1P-0P-0BRA	1989	BRAZIL
OCEPAR 17	OCEP17	KAL/BB//ALD/3/B7408 CM53596-1M-3F-2Y-0P-0BRA	1989	BRAZIL
OCEPAR 18	OCEP18	VEERY CM33027-F-3M-3Y-1M-0Y-100Y-0B-0BRA	1990	BRAZIL
OCEPAR 19	OCEP19	ALD/PVN CM49901-9Y-1Y-1M-3Y-0M-0BRA	1990	BRAZIL
OCEPAR 21	OCEP21	CEP7780/4/KAL/BB//CJ/3/ALD CO3242-2P-19T-13T-0T-0BRA	1992	BRAZIL
PAMIR-94	PAM84	YMH/TOB//MCD/3/LIRA SWM12289-7M-0M-8M-1M-3WM-0WM-0AFG	1994	AFGHANISTAN
PASA	PASA	BUC/CHAT	1989	KENYA
PASBAN 90	PASBAN	TIA	1991	PAKISTAN

APPENDIX 1. CONTINUED.

NAME	ABR	PEDIGREE / SELECTION HISTORY	YEAR	COUNTRY
Bread Wheat				
PASEENA 90	PA90	KVZ/3/TOB/CTFN//BB/4/BLO/5/VEE5/6/BOW/3/ YD//BB/CM75650-C-1M-1Y-3M-3Y-0B-0PAK	1990	PAKISTAN
PIRSABAK 92	PSB92	CM59123-3M-1Y-2M-1Y-2M-2Y-0M-0PAK	1992	PAKISTAN
POTE	POTE	F73.71/TORIM//BJY/JUP	1992	ZIMBABWE
PROINTA FEDERAL	PIFED	BOBWHITE CM33203-H-8M-8Y-1M-1Y-1M-0Y-1T-1T-0T-0ARG	1989	ARGENTINA
PROINTA GUAZU	PIGU	JUP/ZP//COC/3/ALDAN CM59185-3J-1B-0J-9J-0J-0ARG	1990	ARGENTINA
PROINTA PIGUE	PIPG	OASIS/TORIM73 SWM7094	1989	ARGENTINA
PROINTA OASIS	PIOS	OASIS/TOR SWM7094-1Y-1Y-0YA-1J-0J-0ARG	1989	ARGENTINA
PWB343	PWB343	ND/VG9144//KAL/BB/3/YACO/4/VEE4 CM85836-0IND	1994	INDIA
RAYON F 89	RAYON	URES*2/PRL CM90315-A-2B-2Y-1B-0Y-0MEX	1989	MEXICO
ROHTAS 90	ROHTAS	TIA W.8461-R-0PAK	1991	PAKISTAN
ROMY 92	ROMY	AU/ROM 1B-1Y-0PTZ-0MDG	1992	MADAGASCAR
SAETA INIA	SAETA	PSN/BOW CM69560-M-2Y-1M-1Y-1M-0Y	1989	CHILE
SALOHY 92	SLH	4777*2//FNK/GB/3/PVN/4/SARA/5/BUC/BUL CM91970-J-0Y-0M-0Y-3M-0Y-0MDG	1992	MADAGASCAR
SAMWHIT 6	SAMW6	PAVON CM8399-0NER	1990	NIGERIA
SAMWHIT 7	SAMW7	BULBUL	1990	NIGERIA
SAMWHIT 8	SAMW8	II54.388/AN/3/YT54/N10B//LR64	1990	NIGERIA
SARIAB-92	SAR92	JUNCO CM33483-C-7M-1Y-0M-0PAK	1993	PAKISTAN
SASARAIB	SASA	VEERY CM33027-F-87B-0Y-0SDN	1992	SUDAN
SCW101	SCW101	VEERY CM33027-F-15M-500Y-0M-76-B-0Y-0ZWE	1990	ZIMBABWE
SERI 82	-	VEERY CM33027-F-15M-500Y-0M-87B-0Y-IRN	1989	IRAN
SORRAI	SORR	BJ/CAL//TOB/8156(R)/3/7C//BB/CNO CM5813-B-1Y-500M-500T-0M-0PRT	1990	PORTUGAL

APPENDIX 1. CONTINUED.

NAME	ABR	PEDIGREE / SELECTION HISTORY	YEAR	COUNTRY
Bread Wheat				
SPIN GHAR-94	SPGH94	SERI*3//BUC/BJY GRG70-G-7Y-5B-0AFG	1994	AFGHANISTAN
STA ANA 90	STA90	-	1990	GUATEMALA
TAHIRY 92	THR	MON/ALDAN CM64239-1Y-1M-1Y-0M-0HL-0/FS-0MDG	1992	MADAGASCAR
TEPOCA T 89	TEPOCA	FALKE CM56744-7Y-2Y-1M-1Y-0M-0MEX	1989	MEXICO
TILILA	TILILA	VEERY CM33027-0MOR	1990	MOROCCO
TOMAS TRONADOR	TTRO	HUAC/AZ//BNQ/FLK CM60607-2Y-1M-1Y-0Y-0ARG	1989	ARGENTINA
TOMAS TUNGATO	TTUP	MD/3/MIDA/MCM//EX/4/NAC SWM10112-6013-1-1-1-0ARG	1989	ARGENTINA
TUA	TUA	MINIVET CM37705-K-2Y-7M-3Y-1M—0Y-0PRT	1989	PORTUGAL
UW 007	UW007	KEA/GH CM76226-1Y-01M-02Y-2B-3Y-0B-0UGA	1991	UGANDA
UW 0003	UW0003	VS73.600/MRL/3/BOW/YR//TRF CM75113-B-5M-1Y-05M-2Y-3B-OY-0UGA	1991	UGANDA
UW 0011	UW0011	2109.36/VEE/4/WRM//KAL/BB/3/KAL/BB//... CM66120-D-1M-1Y-1M-1Y-1M-0Y-0UGA	1991	UGANDA
UW 0027	UW0027	ULC/PNV//VEE CM67768-RW5-RW5-RW5-RW4-RW0-0UGA	1991	UGANDA
VERANO S 91	VER91	- TC820007-07C-05R-08C-7R-0C-0MEX	1991	MEXICO
VONY 92	VONY	KITE/GLEN CM-3Y-0H-0Y-5M-0Y-0MDG	1992	MADAGASCAR
W2005	W2005	BB/GLL/3/T.AEST.//KAL/BB CM34555	1989	TANZANIA
WARI-INIAA	WARI	BON/YR/3/F35.75//KAL/BB CM41860-A-5M-2Y-2M-1Y-OM-0PER	1991	PERU
XELAJU 91	XJ91	PF72640/PF7326//PF7065/ALD/3/VEE CM81131-26Y-03M-0Y-3M-1Y-0M-0GTM	1991	GUATEMALA
Durum Wheat				
ACONCHI89		ALTAR84/AOS CD67124	1989	MEXICO
BENI SUEF I	-	JO/AA//FG CM9799	1990	EGYPT
BRACHOUA	-	FGO/3/GS/TC60//MEXI_1 CD26701-0AP-1AP-0AP	1990	LIBYA, SYRIA MOROCCO

APPENDIX 1. CONTINUED.

NAME	ABR	PEDIGREE / SELECTION HISTORY	YEAR	COUNTRY
Durum Wheat				
FOKA	-	CIT71/CII CD3369-2BS-2BS-0DZ	1993	ETHIOPIA
KABIR	-	OVI65/CPP//FGO CD12889	1990	ALGERIA
KARIM	-	JP/AA//FGO CM97990-0TVN	1990	LIBYA
KILINTO	-	ILLUMIO/INRAT69//BOOHAI/3/HORA/JORRO/4/CIT71 DZ918	1993	ETHIOPIA
KORIFLA	-	S1S/CRA//GEI-D CD523-3Y-1Y-2M-0Y-0AP	1990	ALGERIA
LAHN	-	SHWA/YAV_2 CD20626	1992	SYRIA
N.A.	-	CHEN/ALTAR84 CD57005	1993	ALGERIA, TUNISIA
OMRABI 3	-	JORI C69/HAU LO589-4L-2AP-3AP-0AP-0LBN	1992	SYRIA, LEBANON,
OMRABI 5	-	JORI C69/HAU LO589-4L-2AP-2AP-0AP	1992	MOROCCO
OMRABI 6	-	JORI C69/HAU LO589-3L-1AP-2AP-1AP-0SH-0AP	1992	ALGERIA
SEBOU	-	CRA/*TRITICUM POLONICUM* ICD79	1989	LEBANON
SOHAGIII	-	MEXI'S'/MAGH//S179/DUR6	1990	EGYPT
TENSIF	-	SCAR/GDOVZ579//YAV_2	1990	LEBANON, SYRIA
		CD26109	1991	MOROCCO
TRITICALE (1991-94)				
ALTER		RHINO	1993	PORTUGAL
AN 34	-	274/320//244.KISS X21748-0Y-1B-2B-T-P-P-P-1B-0Y	1993	MEXICO
AN 36	-	URSS#3310 X-9M-0Y-1Y-2B-1B-1B-0Y	1993	MEXICO
ARANUI		TOPO	1991	NEW ZEALAND
ARRUDA	-	GNU B9612-054-4Y-2Y-0M	1991	PORTUGAL
BANJO	-	MERINO/JLO B2736	1991	CANADA
BORHAN	-	-	1994	MOROCCO
BURA	-	CABORCA 79	1991	CANADA

APPENDIX 1. CONTINUED.

NAME	ABR	PEDIGREE / SELECTION HISTORY	YEAR	COUNTRY
TRITICALE (1991-94)				
CEP 23	-	TATU B5644-777-1Y-0M-0A	1992	BRAZIL
CEP 25	-	STIER B6712-171-11Y-4Y-0M-0A	1992	BRAZIL
CRATO	-	STIER B6712-168-8Y-2Y-0M	1991	PORTUGAL
EMBRAPA 17	-	TATU B5644-777-1Y-0M-0FGS	1992	BRAZIL
EMBRAPA 18	-	TAPIR/YOGUI//2*MUS CTM15082-19M-23Y-0M-0Y	1992	BRAZIL
FIRDAWS	-	-	1994	MOROCCO
GENU-UNCR		ALABAMA ADM 31-0B-0Y	1992	ARGENTINA
HUAMANTLA	-	MUS/BTA X65985-5M-3Y-2M-1Y-4M-1Y-1M-0Y	1994	MEXICO
IAC 2	-	TARASCA	1992	BRAZIL
KARERE	-	BOK=BGL//M2A/CIN	1991	NEW ZEALAND
NINCA	-	TC XII 35-0B-0Y	1992	ARGENTINA
PARMA	-	KISS//193-803/358 B81-420-S006	1993	USA
QUINE	-	BGL/IRA X21538-2M-2M-0Y	1992	ARGENTINA
SANDRO	-	STIER	1992	SWITZERLAND
SUNLAND	-	MERINO/JLO B2736	1991	USA
TCL 82	-	COORONG//AV/DOVE CIT1312-3Y-4Y-503Y-0B	1993	TUNISIA
TCL 83	-	MUS/BTA X65985-5M-3Y-2M-1Y-4M-1Y-1M-0Y	1993	TUNISIA
THOMAS SALADO	-	-	1991	ARGENTINA
TIZNÉ	-	CACHIRULO/M2A X21971-1Y-1Y-0Y-0B	1992	ARGENTINA

CIMMYT Wheat Special Reports In Press or Completed (As of January 1, 1995)

In Press

Wheat Special Report No. 17. Huerta, J., and A.P. Roelfs. 1995. The Virulence Analysis of Wheat Leaf and Stem Rust on a Worldwide Basis.

Wheat Special Report No. 31. Reynolds, M.P., O.A.A. Ageeb, J. Cesar-Albrecht, G. Costa-Rodrigues, E.H. Ghanem, R.R. Hanchinal, C. Mann, L. Okuyama, L.B. Olugbemi, G. Ortiz-Ferrara, S. Rajaram, M.A. Razzaque, J.P. Tandon, and R.A. Fischer. 1995. The International Heat Stress Genotype Experiment: Results from 1990-1992.

Wheat Special Report No. 37. Skovmand, B. 1995. Wheat Cultivar Abbreviations. Paper and diskette versions. Scheduled for printing and distribution in March 1995 as part of GRIP (Genetic Resource Information Package). Listed as Special Report No. 4 in some previous lists.

Printed and Distributed

Wheat Special Report No. 1. Burnett, P.A., J. Robinson, B. Skovmand, A. Mujeeb-Kazi, and G.P. Hettel. 1991. Russian Wheat Aphid Research at CIMMYT: Current Status and Future Goals. 27 pages.

Wheat Special Report No. 2. He Zhonghu and Chen Tianyou. 1991. Wheat and Wheat Breeding in China. 14 pages.

Wheat Special Report No. 3. Meisner, C.A. 1992. Impact of Crop Management Research in Bangladesh: Implications of CIMMYT's Involvement Since 1983. 15 pages.

Wheat Special Report No. 4. Nagarajan, S. 1991. Epidemiology of Karnal Bunt of Wheat Incited by *Neovossia indica* and an Attempt to Develop a Disease Prediction System. Mexico, D.F.: CIMMYT. 69 pages.

Wheat Special Report No. 5. Rajaram, S., and M. van Ginkel. 1994 (rev.). A Guide to the CIMMYT Bread Wheat Section. 57 pages.

Wheat Special Report No. 6. Meisner, C.A., E. Acevedo, D. Flores, K. Sayre, I. Ortiz-Monasterio, and D. Byerlee. 1992. Wheat Production and Grower Practices in the Yaqui Valley, Sonora, Mexico. 75 pages.

Wheat Special Report No. 7a. Fuentes-Davila, G. and G.P. Hettel, eds. 1992. Update on Karnal Bunt Research in Mexico. 38 pages.

Informe Especial de Trigo No. 7b. Fuentes-Davila, G., y G.P. Hettel, eds. 1992. Estado actual de la investigación sobre el carbón parcial en México. 41 pages.

Wheat Special Report No. 8. Fox, P.N., and G.P. Hettel, eds. 1992. Management and Use of International Trial Data for Improving Breeding Efficiency. 100 pages.

Wheat Special Report No. 9. Rajaram, S., E.E. Saari, and G.P. Hettel, eds. 1992. Durum Wheats: Challenges and Opportunities. 190 pages.

Wheat Special Report No. 10. Rees, D., K. Sayre, E. Acevedo, T. Nava Sanchez, Z. Lu, E. Zeiger, and A. Limon. 1993. Canopy Temperatures of Wheat: Relationship with Yield and Potential as a Technique for Early Generation Selection. 32 pages.

Wheat Special Report No. 11. Mann, C.E., and B. Rerkasem, eds. 1992. Boron deficiency in Wheat. 132 pages.

Wheat Special Report No. 12. Acevedo, E. 1992. Developing the Yield Potential of Irrigated Bread Wheat: Basis for Physiological Research at CIMMYT. 18 pages.

Wheat Special Report No. 13. Morgunov, A.I. 1992. Wheat Breeding in the Former USSR. 34 pages.

Wheat Special Report No. 14. Reynolds, M., E. Acevedo, O.A.A. Ageeb, S. Ahmed, L.J.C.B. Carvalho, M. Balata, R.A. Fischer, E. Ghanem, R.R. Hanchinal, C.E. Mann, L. Okuyama, L.B. Olegbemi, G. Ortiz-Ferrara, M.A. Razzaque, and J.P. Tandon. 1992. Results of the 1st International Heat Stress Genotype Experiment. 19 pages.

Wheat Special Report No. 15. Bertschinger, L. 1994. Research on BYD Viruses: A Brief State of the Art of CIMMYT's Program on BYD and Its Future Research Guidelines. 39 pages.

Wheat Special Report No. 16. Acevedo, E., and G.P. Hettel, eds. 1993. A Guide to the CIMMYT Wheat Crop Management & Physiology Subprogram. 161 pages.

Wheat Special Report No. 18. Bell, M.A., and R.A. Fischer. 1993. Guide to Soil Measurements for Agronomic and Physiological Research in Small Grain Cereals. 40 pages.

Wheat Special Report No. 19. Woolston, J.E. 1993. Wheat, Barley, and Triticale Cultivars: A List of Publications in Which National Cereal Breeders Have Noted the Cooperation or Germplasm They Received from CIMMYT. 68 pages

Wheat Special Report No. 20. Balota, M., I. Amani, M.P. Reynolds, and E. Acevedo. 1993. An Evaluation of Membrane Thermostability and Canopy Temperature Depression as Screening Traits for Heat Tolerance in Wheat. 26 pages.

Informe Especial de Trigo No. 21a. Moreno, J.I., y L. Gilchrist S. 1994. La roña o tizón la espicga del trigo. 25 pages.

Wheat Special Report No. 21b. Moreno, J.I., and L. Gilchrist S. 1994. Fusarium head blight of wheat. 25 pages.

Wheat Special Report No. 22. Stefany, P. 1993. Vernalization Requirement and Response to Day Length in Guiding Development in Wheat. 39 pages.

Wheat Special Report No. 23a (short version). Dhillon, S.S., and I. Ortiz-Monasterio R. 1993. Effects of Date of Sowing on the Yield and Yield Components of Spring Wheat and Their Relationships with Solar Radiation and Temperature at Ludhiana (Punjab), India. 33 pages.

Wheat Special Report No. 23b (long version). Dhillon, S.S., and I. Ortiz-Monasterio R. 1993. Effects of Date of Sowing on the Yield and Yield Components of Spring Wheat and Their Relationships with Solar Radiation and Temperature at Ludhiana (Punjab), India. 83 pages.

Wheat Special Report No. 24. Saari, E.E., and G.P. Hettel, eds. 1994. Guide to the CIMMYT Wheat Crop Protection Subprogram. 132 pages.

Wheat Special Report No. 25. Reynolds, M.P., E. Acevedo, K.D. Sayre, and R.A. Fischer. 1993. Adaptation of Wheat to the Canopy Environment: Physiological Evidence that Selection for Vigor or Random Selection May Reduce the Frequency of High Yielding Genotypes. 17 pages.

Wheat Special Report No. 26. Reynolds, M.P., K.D. Sayre, and H.E. Vivar. 1993. Intercropping Cereals with N-Fixing Legume Species: A Method for Conserving Soil Resources in Low-Input Systems. 14 pages.

Wheat Special Report No. 27. Yang Zhuping. 1994. Breeding for Resistance to Fusarium Head Blight of Wheat in the Mid- to Lower Yantze River Valley of China. 16 pages.

Wheat Special Report No. 28. Rees, D., L. Ruis Ibarra, E. Acevedo, A. Mujeeb-Kazi, and R.L. Villareal. 1994. Photosynthetic Characteristics of Synthetic Bread Wheats. 40 pages.

Wheat Special Report No. 29. Rajaram, S., and G.P. Hettel, eds. 1995. Wheat Breeding at CIMMYT: Commemorating 50 Years of Research in Mexico for Global Wheat Improvement.

Wheat Special Report No. 30. Delgado, M.I., M.P. Reynolds, A. Larqué-Saavedra, and T. Nava S. 1994. Genetic Diversity for Photosynthesis in Wheat under Heat-Stressed Field Environments and Its Relation to Productivity. 17 pages.

Wheat Special Report No. 32. Bell, M.A., and R.A. Fischer. 1994. Guide to Plant and Crop Sampling: Measurements and Observations for Agronomic and Physiological Research in Small Grain Cereals. 66 pages,

Wheat Special Report No. 33. Bell, M., R. Raab, and A. Violic. 1994. Setting Research Priorities for Agronomic Research: A Case Study for Wheat in Chalco, Mexico. 20 pages.

Wheat Special Report No. 34. Bell, M.A. 1994. Four Years of On-Farm Research Results at Chalco, Mexico. 35 pages.

Wheat Special Report No. 35. Bell, M.A., H.A. Muhtar, J.A. Stewart, and F. Gonzalez. 1994. Assessment and Development of an Agricultural Research Station: Physical and Personnel Needs. 16 pages.

Wheat Special Report No. 36. Dubin, H.J., and H.P. Bimb. 1994. Studies of Soilborne Diseases and Foliar Blights of Wheat at the National Wheat Research Experiment Station, Bhairahawa, Nepal. 30 pages.

ISSN: 0187-7787
ISBN: 968-6923-38-1

International Maize and Wheat Improvement Center
Centro Internacional de Mejoramiento de Maíz y Trigo
Lisboa 27, Apartado Postal 6-641, 06600 México, D.F., México