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CIMMYT'S WHEAT PROGRAM OVERVIEW

Byrd C. Curtis¹

Introduction

In this overview, I will discuss the goal, organization, philosophy, major breeding strategies, and future program objectives of the CIMMYT wheat program.

The wheat program conducts its activities within CIMMYT's broad mandate "to promote and carry out, nationally and internationally, programs to improve all aspects of maize and wheat production," and strives to contribute its share toward attainment of CIMMYT's institutional goal, which is to improve the productivity of the human, natural, and institutional resources committed to maize and wheat production.

The basis of CIMMYT's breeding programs in bread wheat, durum wheat, and triticale existed in Mexico before CIMMYT's founding in 1966. Bread wheat breeding is now entering its 44th year in the country. The first efforts in durum wheat breeding started in the early fifties, but there was no major work until the late sixties. Triticale breeding began in 1965. CIMMYT's wheat program conducts research on these crops at headquarters and in regional and national programs. It views its role as improving wheat production in developing countries and assisting in the development of national wheat research programs.

CIMMYT's Goal

Our goal is to continually develop widely adapted input-responsive bread wheat, durum wheat, triticale, and barley germplasm, primarily for distribution to the developing countries and to assist those same countries in the development of national wheat research programs. The CIMMYT-developed wheat germplasm varieties generally are photoperiod insensitive, disease resistant, and tolerant to environmental stresses.

Today more than 45 million hectares (ha) in the developing world are planted to high-yielding varieties (HYV's) and most of these are direct from or have CIMMYT germplasm in their pedigrees. Another 15 million ha of such wheat is being grown in the developed world.

How the CIMMYT Wheat Program is Organized

In Mexico, the program is organized into commodity breeding and base research support. The outreach program is divided into regional and bilateral programs. The crop programs are further subdivided into bread wheat, durum wheat, triticale, and barley. International Center for Agricultural Research in the Dry Areas (ICARDA) staff stationed at CIMMYT conduct the barley program. Research support includes germplasm development, germplasm bank, international nurseries that distribute the products of our programs, a training program, agronomy program, industrial quality, seed health, and wide crosses. Pathology is a special activity of support to all breeding programs. The regional programs are located in the Andean region, the southern cone, north and west Africa, the Middle East, eastern and southern Africa, and south and southeast Africa. We have scientists in all of those regions at the present time. The bilateral programs are in Peru, Turkey, Pakistan, and Bangladesh.

In 1985, the wheat program funds were divided into 63 percent unrestricted, 20 percent restricted, and 17 percent extra core. Core unrestricted funds can be used to support any

¹Director, CIMMYT Wheat Program. This chapter was extracted from a transcript of his meeting presentation.

core research activity at our discretion within the mandate. Core restricted funds may be used to support only specific core research activities. Extra core funds are those used to conduct special projects, such as bilateral and some regional projects.

Key Breeding and Development Strategies

Shuttle breeding and multilocation testing, key strategies that come into play for all four breeding programs, are described below.

Shuttle Breeding

The centerpiece research methodology used by all three programs is the shuttle breeding concept established by Norman Borlaug in the late forties. He crossed, screened, and selected germplasm during winter and summer cycles each year at two diverse locations, Ciudad, Obregon and Toluca, Mexico. Today, the winter cycle still takes place at the Mexican government's Northwestern Agricultural Research Station (CIANO), an irrigated desert environment near Ciudad, Obregon in the state of Sonora at 27.2oN latitude, 39 m elevation. Here, breeding materials are crossed and resulting progenies are evaluated for their yield potential under high fertility, well watered situations, and reduced irrigation, as well as screened for resistance to leaf and stem rusts. Samples of germplasm selected for quality evaluations are also taken from material grown at this station. Plantings are made at CIANO in November and early December. Selection and harvest are completed by early May. Seed harvested at CIANO is "shuttled" for May and June planting at the beginning of the summer cycle at CIMMYT's research station in the central highlands near Toluca (elevation 2,640 m and 19oN latitude) and headquarters at El Batan (elevation 2,240 m and 19oN latitude). At Toluca, breeding materials are also crossed and the germplasm is screened for resistance to all three rusts, as well as to septoria tritici blotch, septoria nodorum blotch, alternaria leaf blight, fusarium head scab, and bacteria such as *Xanthomonas campestris* pv. *translucens* and Barley Yellow Dwarf Virus (BYDV). Only limited yield and quality evaluations are made with the material grown at Toluca because of the extremely high disease pressure. At El Batan, germplasm is further screened for leaf-rust resistance and drought tolerance.

The basis of the broad adaptation of CIMMYT materials is insensitivity to day length. In many varieties, flowering is triggered by the onset of days of a certain length. While there are some biological advantages in certain regions in day-length sensitivity, it is usually futile to plant such varieties outside their normal growing season. Differences in day length may make flowering occur too early, too late, or if day length never reaches the critical duration, not at all.

CIMMYT's practice of producing two generations a year at different locations eliminates day-length-sensitive germplasm. From November to May, breeding and selection take place at CIANO where the crop develops as days get longer. From May to November, lines grown at Toluca/El Batan develop as the days are getting shorter. Only materials that are insensitive to this variation in day length are selected. In addition to elevation, day length, and latitude, CIANO and Toluca/El Batan differ markedly in soil type, rainfall amount and intensity, temperature, and diseases. Only those genotypes that withstand the rigors of these locations are advanced for further use in the program.

In addition to CIANO, Toluca, and El Batan, CIMMYT uses a number of "off-station" sites in Mexico. During the summer cycle, all germplasm selected in the low fertility and reduced irrigation nurseries at CIANO are further evaluated for yield potential at the semiarid Huamantla station. Also during the summer cycle, additional testing is done at Patzcuaro (for resistance to the septorias and scab) and Tepatitlan (for leaf-rust resistance). During the winter cycle, additional testing is done at Los Mochis (for tolerance to heat and leaf-rust

resistance), Rio Bravo (leaf-rust resistance), Poza Rica (helminthosporium resistance), and Bajío (agronomic type and resistance to stripe rust).

The shuttle breeding technique that has proven to be so effective in Mexico is also working extremely well on an international basis. The best example is CIMMYT's collaboration with Brazilian scientists, which began in 1973. This project's goal has been to develop high-yielding wheat varieties with tolerance to aluminum-acid soil conditions. Several low-yielding Brazilian wheats with outstanding tolerance to high levels of soluble aluminum were initially crossed with several high-yielding, broadly adapted Mexican semidwarf wheats that were highly susceptible to aluminum toxicity. The segregating populations were grown at three acid-soil locations in southern Brazil, and the selections were shuttled between Brazil and CIMMYT's main breeding sites in Mexico.

Strong selection pressure for tolerance to aluminum toxicity was applied in each Brazilian location, and selections were made for good agronomic type, stem and leaf-rust resistance at CIANO and for all three rusts and a complex of leaf diseases in Toluca. In recent years, nine cultivars obtained through this selection method have been recommended for cultivation in several Brazilian states.

In response to requests from the Chinese Academy of Agricultural Sciences, CIMMYT has also begun a small-scale shuttle breeding program between Mexico and China to develop scab-resistant spring wheats for the Yangtze River Valley and to improve winter wheat germplasm appropriate for conditions prevalent in northern and central China.

International shuttle breeding projects have recently been expanded to include Kenya and Ethiopia (resistance to the rusts) and Nepal (helminthosporium resistance). A further expansion of shuttle breeding is envisioned for the immediate future, for example, Paraguay (heat tolerance) and Morocco (drought tolerance).

Multilocation Breeding and Testing

CIMMYT wheat and triticale germplasm is developed for high-yield potential, broad adaptation, and resistance to three principal wheat diseases--stem rust, leaf rust, and stripe rust. The accretion of these characteristics in CIMMYT-developed germplasm is a direct result of multilocal breeding and testing.

Advanced generation breeding materials that have passed the rigors of selection at all locations in Mexico are yield-tested at CIANO during the winter cycle. The best performing genotypes are then entered into nurseries for international testing and distributed to cooperators around the world. In 1986, international bread wheat nurseries from CIMMYT were grown in 199 sites in 88 countries; durum wheat nurseries were grown in 62 countries, and triticale nurseries were grown in 79 countries.

Results from these nurseries provide information on adaptive ability, yield performance, and resistance to the major diseases of a broad spectrum of germplasm. These data are used to further improve the genetic characteristics of CIMMYT germplasm for a wide range of traits. It is our belief that a great deal of the success achieved by CIMMYT germplasm is the direct result of multilocation testing--in fact, it is one aspect that few breeding programs in the world enjoy. It is undoubtedly the key reason for the widespread adoption of CIMMYT's germplasm in developing and developed countries.

Breeding for Disease Resistance

One of the central objectives of the CIMMYT bread wheat, durum wheat, and triticale programs continues to be the development of disease-resistant germplasm for worldwide

distribution. Success in breeding for disease resistance is heavily dependent on international multilocal testing. The international nursery system permits the exposure of materials to a wide range of virulence for the different diseases. Performance data returned from cooperators are used to calculate the average coefficients of infection (ACI) for various diseases in numerous locations.

For rusts, a line that shows a consistently low ACI at diverse locations is presumed to carry multiple genes for resistance. Lines with low coefficients for rusts and other diseases are used in simple and three-way crosses to pyramid the resistance genes. The segregating progeny are then exposed to as many diseases as possible in the field to eliminate those that do not have broad resistance. When germplasm combines broad-based disease resistance with production potential, it is returned as advanced lines to national programs for retesting, further selection, or possible release.

Dr. Norman Borlaug and his team emphasized resistance to stem rust in the fifties and sixties, because it was the disease causing great problems. Then in the seventies the emphasis shifted to leaf rust, stripe rust, and septoria leaf blotch. In the eighties, our efforts have expanded to include helminthosporium and fusarium scab.

Today's CIMMYT spring bread wheat germplasm has a good level of stem, leaf, and stripe rust resistance and tolerance to septoria leaf blotch in some sub-sets. Progress has been made on incorporating resistance to helminthosporium and fusarium scab, but much work remains to be done.

Aid in Priority Setting

The information returned by the cooperators also helps CIMMYT to plan future crosses as well as set the priorities and direction of the three programs. This research methodology, using the information derived from the international nurseries in CIMMYT's crossing program in Mexico, followed by the selection of superior advanced genotypes at testing sites in Mexico and other locations, has proved to be an extremely effective breeding strategy for the bread wheat, durum wheat, and triticale programs.

This approach to breeding permits timely response to changing circumstances and priorities. It also enables the rapid development and distribution of new germplasm that reflects the needs and realities of national programs around the world.

Germplasm for Megaenvironments

The research priorities adopted by the bread wheat, durum wheat, and triticale programs are shaped by the exigencies of crop production in certain large target areas. As seen by CIMMYT, each of these target areas, termed mega-environments, comprises more than 1 million ha worldwide. Megaenvironments are based on the main varietal characteristics needed by local farmers. They are relatively uniform in moisture, soil type, temperature regime, and biotic stresses. Each breeding program emphasizes broad adaptation within these megaenvironments.

Significant mega-environments are usually found on more than one continent. For example, the durum wheat program deals with a semiarid megaenvironment that includes such locations as northern and southeastern Argentina, central Mexico, central and southwestern Morocco, central Algeria, southern Cyprus, central India, and China near Mongolia and Xinjiang.

The megaenvironments for which the wheat program develops its materials comprise the following areas in which wheat is a major food crop or its consumption is rising quickly:

- 1) Well watered areas, generally irrigated;
- 2) Rainfed areas (more than 500 millimeters (mm) annually) with potential drought stress;
- 3) Rainfed, semiarid areas, occasionally-drought stressed (350-500 mm annually);
- 4) Rainfed, drought-stressed areas (less than 300 mm annually);
- 5) Acid soil areas where wheat production is limited by aluminum and other mineral toxicities or deficiencies; and
- 6) Warmer areas where sudden increases in temperature are common.

Priority Regions

Priority regions for our breeding programs are the following:

- 1) North Africa and Middle East comprise roughly 15.5 million ha, largely in Turkey, Algeria, and Morocco. Constraints of this priority area are stripe rust, leaf rust, stem rust, and drought.
- 2) Eastern and Southern Africa. There is not a great deal of wheat except in Ethiopia (600,000 ha and increasing). Kenya has been pretty stable at about 100,000 ha. The constraints are stem rust, leaf rust, septorias, helminthosporium, and acid soils.
- 3) Asian subcontinent. This region has 31 million ha in wheat (22 million in India, 8 million in Pakistan, and rest in three other countries). Main constraints are leaf rust, stripe rust, stem rust (not much of a problem), Karnal bunt, loose smut, alternaria diseases, short-growing season, and the drought problem.
- 4) Southern Cone of South America. Countries without soil aluminum problems are Argentina, Chile, Uruguay, and Paraguay. There are almost 7 million ha in wheat, largely in Argentina. Constraints include the three rusts, septoria leaf blotch, occasionally fusarium head scab, bacteria, and drought. In the Southern Cone, Brazil has more than 1.7 million ha of acid soils now producing wheat (with more expected) where the primary problem is a toxic level of aluminum in the soil which adversely affects the wheat crop. Constraints include stem rust, leaf rust, septorias, fusarium head scab, aluminum toxicity, low phosphorus availability, and drought.
- 5) Andean Region. Not much wheat is grown, but for many resource-poor farmers, it is an important crop. Constraints include stripe and leaf rusts, various root diseases, insect problems, high temperatures in low elevations, and poor soils in much of the highland areas (poor fertility and some acid soils).

Future Program Projections

Maintenance Research

As indicated earlier, a majority of the wheat program resources is allocated to bread wheat activities. We anticipate that this level of support must continue because bread wheat predominates in the developing world and a large proportion of the total resources allocated are involved in maintenance research, that is, maintaining advances already made. This type of research is essential for continued output of improved germplasm leading to varieties with high-yield potential and good resistance to the prevalent diseases. Pathogens causing diseases tend to mutate rapidly, thereby, rendering previously resistant varieties susceptible to the new virulences. It is impossible to calculate accurately the amount of resources allocated to the wheat program's maintenance research, but undoubtedly it more than doubles the amount dedicated to germplasm improvement.

Maintenance research is less important in the durum wheat and triticale programs because, at their current stages of progress, more resources are needed to achieve what already has been accomplished in the bread wheat program. Intensive developmental activities will be required in the medium term to develop germplasm that has broad adaptation, high-yield potential, and resistance to the major diseases. Once this has been achieved, more resources will be shifted to maintenance research and less will be devoted to development.

Shifting Priorities and Resources

The wheat program anticipates a greater research input for the world's marginal wheat areas. As more resources are allocated to the marginal environments, additional biotic and abiotic constraints will be identified. And as has occurred in the past, the identification of new constraints will require CIMMYT to shift its priorities.

For example, when farmers started growing wheat in the acid soils of Brazil with its inherent levels of free aluminum, the toxicities that were present depressed yields. CIMMYT responded by shifting resources toward the development of aluminum-tolerant wheats. To help farmers in more tropical countries, CIMMYT has initiated a program to develop wheats with better heat tolerance and resistance to the prevalent diseases. Currently, CIMMYT is giving more attention to tolerance to drought and heat and resistance to scab, helminthosporium, and BYDV. However, in the future, we may be confronted by new problems caused by abiotic or biotic stresses that will significantly affect wheat production. When this happens, CIMMYT will be ready to shift priorities and resource allocations accordingly.

Crop Management

The CIMMYT wheat program expects to give additional support to crop management. It is evident that improved production technologies must be developed for and adopted by farmers in many developing countries before the genetic potential of the available varieties can be fully exploited. CIMMYT believes it has a role in this activity and will commit the necessary staff and financial resources to achieve this objective within the context of the program. Resource allocation to crop management research will likely increase during the next decade, particularly in the regional and bilateral programs as we attempt to post crop production specialists in each region.

Training National Scientific Staff

Another vital component of the development of national research programs is scientific staff training. CIMMYT has committed a large proportion of its staff and financial resources to training for many years and will continue to do so. As the number of cooperating countries grows (for example, nontraditional wheat countries), there is a great need to train scientists because most of these countries lack trained wheat researchers. Of course, there are still training needs within the established research programs because of staff turnover and priority changes.

Current training activities in crop improvement will probably satisfy national program requirements, but training in crop production techniques needs to be expanded. With existing staff and financial resources, it is impossible to satisfy these needs and CIMMYT must work with other organizations (such as advanced national programs) to provide required production training. CIMMYT must also seek means of multiplying the effect of its training courses by using in-country training, workshops, and conferences.

Shifting Research to Developing Countries

Several of the more advanced countries within the developing world (such as India, Argentina, Pakistan, Turkey, Brazil, and Mexico) have a large number of trained staff members and well organized research programs. CIMMYT will make every effort to develop more partnership research projects with the national programs of these countries. These projects will be tailored to the specific strengths of the various national programs and to their priorities. Going one step further, some of the collaborative research, currently being conducted by research institutes in the developed world, may soon be shifted to institutes in the developing world.

More Shuttle Breeding

The wheat program hopes to develop more extensive shuttle breeding relationships with selected countries. The shuttle program with Brazil has been extremely successful and has benefited not only Brazil but also CIMMYT's effort to develop better germplasm for other countries. The efforts underway with China, Nepal, and Paraguay should yield similar results in the near- and mid-term. Another shuttle program is planned with Morocco. New shuttle breeding programs will undoubtedly be established because this method allows CIMMYT and the cooperating country to develop germplasm with a combination of traits that would be impossible if only one site were available for selection. This combination of traits is frequently beneficial to other countries as well.

Additional Networks

The core of CIMMYT's wheat program revolves around its international nursery network. This network has provided valuable information to CIMMYT breeders and pathologists and has greatly facilitated the development of germplasm that is grown in most developing countries. This network has also been highly beneficial in developing a team of wheat researchers who have worked together to resolve common problems.

With the success of this particular network in mind, CIMMYT is trying to develop additional networks for other research priorities. A recent example is the BYDV network of developing and developed countries of which CIMMYT serves as the "hub." Efforts are also underway to develop pathology networks for research on rusts and scab, helminthosporium, septoria, and bacterial diseases. A rice-wheat production management research network is in the planning stages for South and Southeast Asia to solve the problems affecting yield sustainability. Other disease networks can be added as priorities change.

Disease Surveillance Program

Since the seventies, CIMMYT has conducted a disease surveillance program. This network of cooperators has helped monitor and survey prevalent diseases and races that exist throughout the world. Preliminary results of the survey have been distributed to cooperators, and during 1987, complete data from the program will be published. The results should help us identify epidemiological zones around the world. We should also obtain some insight on the dissemination of new races from one country to another.

These results have been obtained with very limited resource input. Since diseases are an important constraint to wheat production in most areas of the world, we believe that additional resources should be given to this activity. In 1987, CIMMYT assigned at least 0.5 scientific man years (SMY) to disease surveillance.

Biotechnology

We believe biotechnology holds promise for the future although little of the new technology is presently applicable to wheat. New methodologies will undoubtedly be perfected that will improve the efficiency of developing germplasm and provide an additional tool in pathological research. When these tools become available, the wheat program will make every effort to incorporate them into the research effort. If additional resources are needed, priorities will be adjusted to accommodate the requirements.

Conclusion

The CIMMYT wheat program has been underway since 1944 when Norman Borlaug was assigned to the Office of Special Studies in Mexico with funding from the Rockefeller Foundation. The name CIMMYT (acronym for Centro Internacional de Mejoramiento de Maiz y Trigo) was adopted in 1966.

During the next 42 years, wheat germplasm was developed which, along with the new rice germplasm from IRRI, led to the green revolution in the late sixties and early seventies. A philosophy of wheat germplasm development and methodologies emerged that have resulted in tremendous gains for wheat farmers in the developing and developed world. These activities are continuing but with a shifting of resources to include more marginal wheat production areas.