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Utilization of Exotic Germplasm in Wheat

Byrd C. Curtis*

Mr. Chairman, it is a pleasure to participate in this, the 75th convening of the American Society of Agronomy. My topic today focusses on an area of continuing interest and concern to the CIMMYT Wheat Improvement Program and to wheat scientists the world over: the effective utilization of exotic germplasm to improve the genetic background and agronomic performance of wheat.

For those of you who may not be familiar with the organization I represent, let me give you a very brief background about CIMMYT, The International Maize and Wheat Improvement Center, located near Mexico City, Mexico. CIMMYT is a non-profit, autonomous agricultural research

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institution dedicated to supporting and complementing the research efforts of developing countries to increase the quantity, dependability, and quality of maize, wheat, barley, and triticale production. CIMMYT's mandate is global and the institute works with virtually every maize- and wheat-producing country in the world.

The development of improved germplasm is CIMMYT's most important objective. While there are some differences in the crop improvement procedures followed by CIMMYT scientists in maize and wheat, both programs adhere to the principle of large-scale multilocational testing and selection networks in which national collaborators play a full partnership role. Both programs seek to develop superior genetic materials with broad adaptability and dependability of yield across many lacations. National collaborators focus on selecting materials and developing varieties that have the best adaptation to local conditions.

As you will see in a few moments, the use of exotic germplasm is an integral, and in fact fundamental, part of CIMMYT's overall breeding strategy. Now, the word "exotic" tends to invoke different images, such as this one, for example, so let me quickly define what is meant here by the term "exotic germplasm". For purposes of this discussion, I have adopted the definition put forth by Hallouer and Miranda (1981) and again by Brown (1982); exotic germplasm includes "... all germplasm that does not have immediate usefulness without selection for adaptation to a given area."

Hybridization

Over the years, great benefits have been derived from exotic germplasm via hybridization with locally adapted wheats. In these instances, the objective is to transfer to the locally adapted varieties specific genes for various desirable agronomic traits. For example, the common and dwarf bunt smut resistance of Pacific Northwest wheats was greatly enhanced by the hybridization of locally adapted varieties with the accession from the country of Turkey, P.I. 178383.

A much more dramatic and well-known example of hybridization using exotic germplasm involves the introduction of the Asian semidwarf gene complex from the variety Norin 10. In 1946, Dr. S.C. Salmon, a USDA scientist acting as an agricultural advisor in Japan, noticed that farmers were growing a number of stiff-strawed, short-stemmed wheat varieties. He collected and sent some of these plant types to the USDA research facilities at Beltsville, Maryland. The rest, as they say, is history. The first commercial semidwarf was released in the USA in 1961. This variety was named Gaines, and was developed from the Norin germplasm by Orville Vogel. Today, there are about 12 million hectares (some 30 million acres) of US wheat land planted to semidwarf varieties. Norman Borlaug received F_2 seed from the Norin 10/Brevor crosses in 1953, and began using this exotic germplasm in his Mexico-Rockefeller Foundation coöperative wheat breeding program in 1954. There are now more than 35 million hectares planted to semidwarf wheats in the developing world, nearly all of which stem from this earlier work by Borlaug and his co-workers.

CIMMYT's Objectives in Using Exotic Germplasm

Since its formation in 1966, CIMMYT has taken a truly global approach to wheat breeding and population improvement, and has emphasized the effective and efficient utilization of exotic germplasm from all over the world. The early years of breeding and agronomic research in Mexico focused on developing a semidwarf plant type, capable of greatly improving wheat production in many of the larger wheat-growing areas of the developing world. During this period, nearly all our efforts were concentrated on irrigated (or irrigable) regions in the Third World, such as the Gangetic and Indus plains of the Indian Subcontinent and the Yaqui Valley in Mexico.

During the last decade, a greater amount of our resources were directed toward addressing the problems of rainfed wheat production. The basic plant type did not change, but greater resistance to the rusts and Septoria tritici was incorporated from various types of exotic germplasm. Agronomic practices designed to enhance cultivation and production in rainfed areas were also developed and promoted. The overall result of these efforts, which were made in close collaboration with the affected national programs, has been a significant increase in wheat production in Argentina, the Middle East and parts of North Africa.

For the decade of the 1980s and beyond, the CIMMYT Wheat Improvement Program is directing its efforts toward improving the level and stability of yields, particularly in the more marginal production environments. Increasing genetic yield potential, per se, will still receive attention, but will not command the highest Program priority. However, we believe that further advances in yield potential will result from the continued use of exotic germplasm in our breeding programs. For example, we are initiating selection procedures to identify wheats that have the ability to produce more biomass and that possess greater photosynthetic efficiency. By using this and other procedures for incorporating exotic germplasm, we feel certain further increases in yield potential are possible.

CIMMYT will continue to give high priority to broad adaptation and yield stability. Wheats with broad adaptation are fundamental to our program, since we work with over 100 different countries representing a multitude of growing conditions. The preliminary steps toward incorporating broad adaptation are taken by our breeding program in Mexico. We use two breeding cycles per year and the materials are grown under widely different environmental conditions. The winter cycle is grown in northwest Mexico near the city of Obregon (27.2° N latitude) at sea level and under irrigation. Selections are made there for yield potential and leaf and stem rust resistance. The summer cycle is grown at a high altitude site, about 2,650 meters above sea level, near the city of Toluca (18.5° N latitude). This site normally receives high rainfall, which encourages severe natural infections of stripe rust, septoria, and other foliar diseases. Germplasm is shuttled between these two locations, and the selection of lines that perform well at both sites has led to a high degree of photoperiod insensitivity in CIMMYT wheats. These broadly adapted wheats are distributed as international nurseries to cooperators around the world, where they are tested under very diverse environmental conditions. The best performing lines from the worldwide testing program are then cycled back through our crossing program to further enhance the broad adaptation of subsequent materials. Lines that are more specifically adapted to a local site can be, and usually are, selected from an array of lines already selected for general broad adaptation.

The shuttle breeding technique that has proven to be so effective in Mexico is also working extremely well on an international basis. In collaboration with Brazilian scientists, CIMMYT began a shuttle breeding program in 1973 to develop high-yielding wheat varieties with tolerance to aluminum toxicity. Aluminum toxicity is among the most important growth-limiting factors affecting wheat production in certain large areas of laterite soils in Brazil, East Africa and parts of Asia. In this cooperative breeding effort, several low-yielding Brazilian wheats with outstanding tolerance to acid soils and high levels of soluable aluminum were initially crossed with several high-yielding, broadly adapted Mexican semidwarf wheats that were highly susceptible to acid soils and aluminum toxicity.

The segregating populations were grown at three acid-soil locations in southern Brazil and the selections were shuttled between Brazil and our main breeding sites in Mexico. Strong selection pressure for resistance to acid soil conditions was applied in each Brazilian location, and selections were made for stem and leaf rust resistance in northwest Mexico and for all three rusts and a complex of leaf-spotting diseases in Toluca. Currently, more than 80 advanced-generation lines are in replicated yield tests and one short-statured, aluminum-tolerant line is being increased for distribution in Brazil. These lines appear to have good tolerance to high levels of soluable aluminum, as well as resistance to the three rusts and, surprisingly, to a complex of leaf-spotting diseases present in both Brazil and Toluca, Mexico. Such progress can only be achieved by applying extreme selection pressure for tolerance to soil stresses and disease resistance in each of the breeding sites, and then shuttling the outstanding segregates between sites.

The Brazilian/CIMMYT shuttle breeding program demonstrates our strong interest in improving the stability of yields across environments. This is a high priority objective that will be achieved mainly by using exotic germplasm to impart broad-based disease resistance and improved tolerances to problem soils and environmental extremes. On the disease front, we will continue to improve the resistance of CIMMYT wheats to the three rusts, but the the levels of resistance are currently adequate for the majority of the developing countries. Acceptable levels of resistance to septoria leaf blotch are now available in CIMMYT germplasm, but higher levels of resistance are desired. We plan to subject our materials to the stronger virulence septorias, as recently reported by Dr. Zahir Eyal in his 1982 virulence survey. Much more emphasis is now being given to the so-called minor diseases of wheat, such as those caused by *Helminthosporium* spp., *Fusarium* spp., *Septoria nodorum*, and barley yellow dwarf virus (BYDV). Sources of resistance to these organisms have been identified and we are in the process of pyramiding resistance genes and incorporating them into high-yielding, semidwarf types.

Sources of Exotic Germplasm Used by CIMMYT

To achieve these and other germplasm development objectives, CIMMYT's Wheat Improvement Program is utilizing a number of different sources of exotic germplasm. Because of the high level of success we have experienced in the past, we are continuing to make thousands of crosses each year within various spring wheat gene pools. However, we are also probing more deeply the numerous genetic combinations possible from crossing spring and winter wheat cultivars. Spring x winter crossing work is not new, but only recently are the payoffs from making a large number of crosses being realized. The recent releases of Vona and Newton winter wheats in Kansas and Colorado are setting new production records in the southern Great Plains. CIMMYT's new Veery lines, for example, which resulted from crossing the exotic Russian winter wheat, Kavkaz, with certain CIMMYT spring wheats, are now setting yield nursery records in many parts of the world under a wide range of growing environments. Kavkaz contains the 1B/1R translocation, which is providing excellent resistance to _Septoria tritici._ There is mounting evidence that this same translocation is also providing better tolerance to aluminum, as well as to higher yield potential.

Intergeneric hybrids

We are also increasing our efforts to transfer useful genes from related genera to wheat. The focus of this kind of intergeneric hybridization work is not the improvement of genetic yield potential, *per se*, but rather increased yield stability through better resistance to diseases and greater tolerance to environmental extremes. Since late 1979, when an experienced cytogeneticist was added to our staff, CIMMYT has been giving considerable emphasis to this activity.

CIMMYT's first major involvement in intergenetic hybridization was with triticale. At present, triticales are competitive in yield with wheat under normal growing conditions. In certain production areas, however, such as those with acid soils, in semitropical highlands, and in some specific disease- and/or drought-prone areas, triticales generally show better adaptation and yield performance than wheat. The remaining obstacles to widespread commercial cultivation center around triticale grain quality and lateness in maturity. We are pleased to report that during each of the last four years, a one kilogram per hectoliter gain in grain weight has been realized. Also, a few lines are now as early as Sonalika wheat, one of the earliest spring wheats in commercial production.

CIMMYT scientists have been crossing wheat with _Aegilops_, _Agropyron_, _Elymus_, _Haynaldia_, and _Secale_ species, and have established a number of collaborative efforts with various centers of excellence in this area. The alien species are being used to transfer to wheat their greater tolerance to environmental stresses, as well as their resistance to diseases.

A recent evaluation of advanced backcross progenies from wheat x *Agropyron* spp. and wheat x *Elymus* spp. indicate good resistance to fusarium head scab and *Helminthosporium sativum*. Scab is an important constraint to wheat production in China, the single largest wheat producer in the Third World, and can also be a devastating disease in other areas. As the production of wheat increases in the warmer, more humid subtropics, scab and *H. sativum* are likely to become major production constraints. To accelerate the development of scab-resistant varieties, CIMMYT is in the process of establishing a shuttle breeding program with China, similar to the Brazilian program. We are also shuttling germplasm between Mexico and Bangladesh to specifically improve resistance to *H. sativum*, and good sources of resistance have been found in CIMMYT germplasm. Since we are trying to develop wheats for the shorter and cooler seasons of the subtropics, added objectives of this shuttle breeding program include the selection of wheats with short growth cycles and heat tolerance on both ends of the cycle.

The preliminary indications of resistance in the backcross progenies mentioned a moment ago are being thoroughly checked and verified. Assuming that the alien chromosomes are, in fact, providing resistance, then it should be possible to transfer this resistance to common wheat by way of existing translocation techniques. The remaining constraints to achieving subtle alien genetic transfers will hopefully soon be overcome. Efforts are underway to transfer such wheat genetic mechanisms as aneuploids of chromosomes 5B to some of the best performing CIMMYT wheats, and then to use these wheats in crosses with the alien species.

Other, and perhaps more traditional, sources of exotic germplasm are also used by CIMMYT. Wheat accessions are located in various germplasm banks around the world, including our own new medium-term storage facility that currently houses some 32,000 entries. In addition, there is widespread exchange of germplasm among the scientists and institutions that constitute our global germplasm distribution network.

THE CIMMYT WHEAT IMPROVEMENT PROGRAM'S GERMPLASM DISTRIBUTION NETWORK

In 1982, collaborating scientists in 98 countries requested 2,568 trials of experimental wheat, barley, and triticale materials from 47 different nurseries. Each nursery consists of a set of lines--sometimes as many as 500 entries--that are constituted to serve the breeding requirements for particular production environments and disease problems. Several general international nursery categories are offered. In addition, a number of regional nurseries--mainly used for disease screening and surveillance--have been implemented in North Africa, the Middle East and parts of Asia, and in South America.

The inclusion in these nurseries of advanced lines and varieties from all parts of the world affords CIMMYT and national cooperators the opportunity to observe the adaptation of materials to widely differing local conditions. The yield nurseries are particularly valuable to those developing country institutions that lack the resources for large-scale breeding programs. Some varieties included in these nurseries are suitable for naming and commercial release without further improvement, permitting almost immediate seed multiplication for commercial production.

Finally, the international exchange of early generation segregating materials provides wheat scientists with a broad base of genetic diversity--an essential ingredient in successful breeding programs. This wealth of germplasm is used as crossing material in many national programs and has resulted in the release of hundreds of improved varieties around the world.

INTERNATIONAL COOPERATION IN PLANT BREEDING

CIMMYT scientists believe that the advent of international nurseries initiated a new era in plant breeding. Before international nurseries were established in the early 1950s, many breeders were reluctant to release advanced lines from their breeding programs to fellow scientists for fear that new varieties would be named and released without the proper recognition of their efforts. Distribution of materials to other scientists was generally delayed until the variety had been named in the breeder's own country. Rarely were early generation materials distributed to other scientists.

International testing ushered in a new willingness to share early generation materials and advanced generation, un-named lines. This, in turn, greatly increased the introduction of materials with genetic variability into national programs and helped break down a psychological barrier that had tended to isolate the efforts of individual plant breeders.

As an example, the CIMMYT-coordinated international wheat improvement network, based on the free and essentially unrestricted exchange of germplasm, has served as a unifying thread to bring together the work of thousands of scientists and hundreds of organizations worldwide.

CIMMYT benefits from international testing by being able to identify materials with broad adaptation and superior performance in terms of yield potential, disease and insect resistance, tolerance to stress, and grain quality. Such materials are used by CIMMYT in future improvement activities, thus reinforcing these useful traits in the subsequent breeding cycles of the germplasm. Simultaneously, national collaborators have had continuous access to a broad and constantly improving germplasm base.

LOOKING TO THE FUTURE

On a global basis mankind depends on the land for 98 percent of its food supply. This dependence is not expected to change significantly over the remainder of this century. In terms of human well-being, the most important food products are the cereals; the grain crops that occupy some 55 percent of the world's cropland area. Wheat, rice, maize, barley and the other cereal grains together supply well over half the food energy consumed directly by people and form a sizable part of the remaining food energy consumed indirectly in the form of livestock products.

Depending on which projection one decides to use, world population will double over the 1975 count in 40, 60 or 80 years. This means that we will have to double world food production within this timeframe, just to keep even with the often inadequate 1975 per capita food levels. We believe that improving not only the level, but the stability of yields on existing croplands will be the major source for the additional production needed to adequately feed the 8 billion people who will be on Earth early in the 21st century.

to conclude this presentation, I would say

that Despite the difficulties facing developing countries, the CIMMYT staff is convinced that, from a biological viewpoint, it is possible to expand agricultural food production over the next 20 years at a rate that will equal or slightly exceed the rate of aggregate population growth. Achieving this increase and distributing it more equitably, however, will require political stability, the determination of national governments to increase investments in their agricultural sector--including research and extension--and the continued sharing of new knowledge and genetic material among the community of nations.