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The CIMMYT's International Approach to Breeding Disease-Resistant Wheat

The wheat breeding program of the International Maize and Wheat Improvement Center (CIMMYT) aims to produce high-yielding, broadly adapted, disease-resistant germ plasm for less-developed countries (LDCs). During 1967–1968, high-yielding, semidwarf wheat cultivars were grown on about 5 million ha in LDCs; by 1976–1977 this had increased to approximately 29 million ha (7). Most of these cultivars are either CIMMYT-derived or lines interbred with CIMMYT germ plasm in national programs. As the area sown with CIMMYT-related germ plasm has increased, the need for broader-based and more stable disease-resistant cultivars has become more important.

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This article describes the strategies used by CIMMYT to increase and stabilize disease resistance in bread wheat. Similar techniques are used in the triticale, durum wheat, and barley breeding programs.

Principal Strategies

Introduction of diversity—stirring the genetic soup. Because wheat cultivars derived from CIMMYT are grown on such large areas and under very different conditions, the germ plasm used must be as diverse as possible. New lines must be developed quickly if they are to be of value to LDCs. Decisions are based on experience and a rapid assessment of the available data rather than on a detailed analysis of each cross. We must avoid the danger of "paralysis by analysis."

CIMMYT grows two generations and makes about 8,000–10,000 crosses each year (4,000–5,000 crosses per generation) (Fig. 1). One generation is grown at Ciudad Obregon, Sonora (27°20′N, 40 m above sea level) and the other at Toluca (19°16′N, 2,649 m above sea level); both sites are in Mexico. At Ciudad Obregon wheat leaf rust (*Puccinia recondita*) and stem rust (*P. graminis*) are prevalent, whereas at Toluca the major disease is stripe rust (*P. striiformis*), although *Septoria nodorum*, *S. tritici*, *Fusarium nivale*, and *F. roseum* occur sporadically.

Fig. 1. This is a common scene at CIMMYT, where bread wheat breeders effect nearly 10,000 crosses per year.

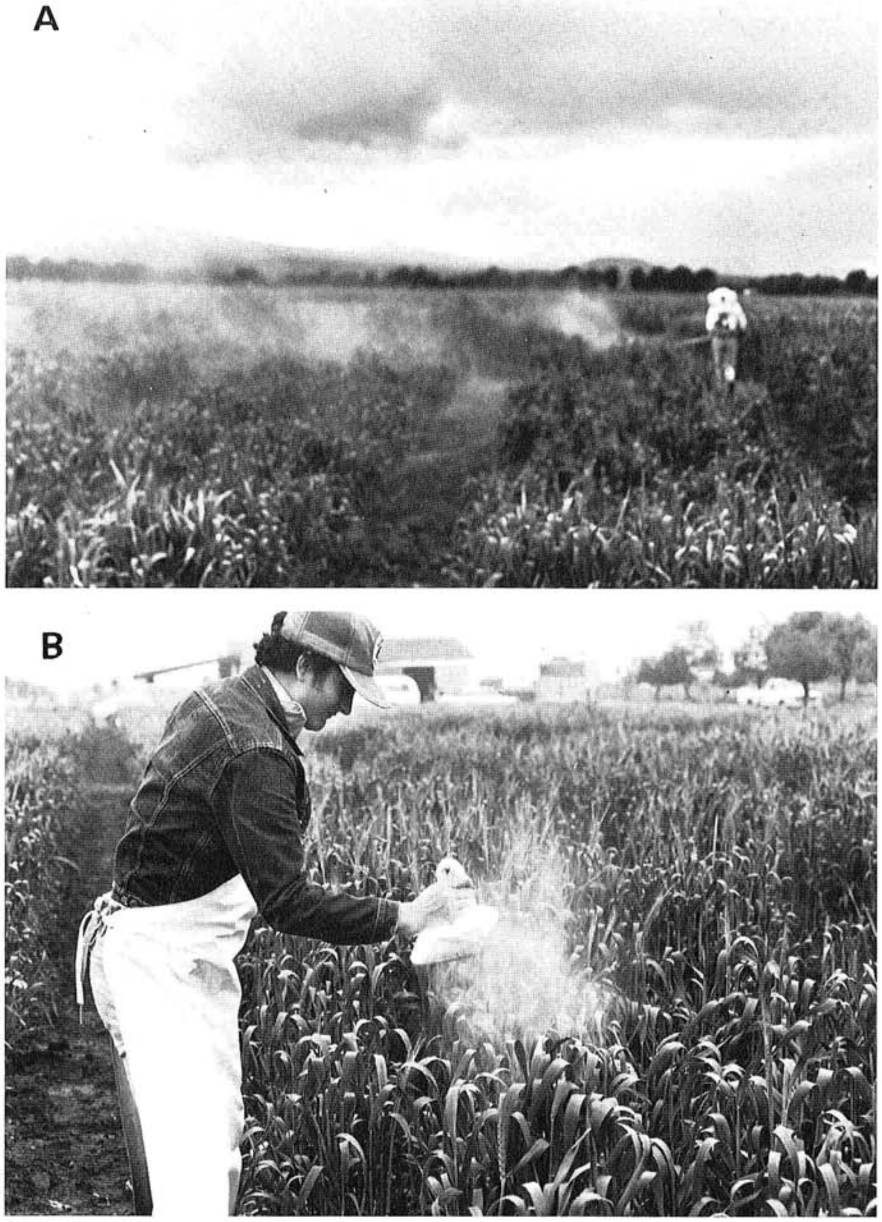

Fig. 2. Breeding nurseries of the CIMMYT wheat program are repeatedly inoculated with uredospores of the leaf and stem rust fungi. Rust collections cover a broad spectrum of virulence combinations. Shown here is one of the inoculation methods, in which spores mixed with talc are dusted on wheat plants. Usually, the most efficient knapsack dusters are used (A); however, visitors from developing countries learn alternative simpler procedures, such as the sifting cloth bag (B).

Table 1. Patterns of leaf rust infection on two advanced CIMMYT wheat lines at six sites[a]

	Advanced line	
	Chiroca sib	Moncho sib
Site	(10th IBWSN entry 106)	(10th IBWSN entry 63)
Natal, South Africa	5R	20S
Sonora, Mexico	10R	20M
Madhya Pradesh, India	TS	50S
Buenos Aires, Argentina	0	10S
Ancash, Peru	TS	40MS
Giza, Egypt	0	TS

[a]Severity of infection assessed in percentage according to modified Cobb scale (3), where 0 = absence of disease and T = trace (less than 5%). Reaction type from R = resistant to S = susceptible, with MR = moderately resistant, MS = moderately susceptible, and M = a blend of MR and MS.

In both generations all segregating and parental nurseries are inoculated with leaf and stem rust uredospores (Fig. 2). Both locally prevalent rust isolates and those with uncommon virulence combinations are used. Border rows are sown with mixtures of universally and differentially susceptible lines to maintain as much diversity as possible in the pathogen.

The germ plasm used in the crosses is obtained from all areas of the world and chosen because it has some useful trait. Figure 3 (in blue) illustrates the movement and handling of materials in the CIMMYT bread wheat breeding program. The numbers of lines differ from year to year but 40–50% of the plants selected from each generation are subsequently discarded because of unacceptable seed characteristics.

Since 1969, CIMMYT has been crossing spring with winter wheat on a large scale (1,000–1,500 each year), in the hope that mixing these relatively isolated gene pools will increase potential yields. Spring wheat may also introduce leaf and stem rust resistance and increase the range of winterhardiness. On the other hand, winter wheat may contribute resistance to drought, stripe rust, and *Septoria* spp. The International Winter × Spring Wheat Screening Nursery (IWSWSN) is derived from selections made at Oregon State University. A complete description of this program is given in CIMMYT Reports on Wheat Improvement (4–6).

As a result of many years experience of cereal breeding, CIMMYT places much emphasis on the pedigree breeding system and use of the top and double cross (Fig. 3, in blue). The double, or four-way, cross permits rapid combination of germ plasm from four parents in 1 year and increases the genetic diversity more quickly than other methods (Fig. 4). Double crosses allow breeders to combine many genes for resistance to one disease at one time and also enable them to combine genes against several diseases rapidly. This is especially important because CIMMYT breeds for diverse climates and regions with many different disease problems.

Multilocation testing—CIMMYT's most important international strategy. Genetic studies have suggested that wheat genotypes resistant to rust diseases in many dissimilar localities, as indicated by low coefficients of infection (14), often contain multiple factors for resistance (11). However, it is not known whether some of this polygenic resistance is race-nonspecific. Nevertheless, if a line contains several functioning resistance genes there is a greater chance that the resistance will be durable. By testing at a number of epidemiologically dissimilar sites, and exposing lines to the greatest possible range of virulence factors, the most durable and useful resistances should be identified.

Obviously, such thorough screening cannot all be done in Mexico, and F_2 bulk populations of the best simple crosses are sent for selection to cooperators in many other countries (Fig. 3, green frame). After several generations, the most promising advanced lines from each area are cycled back into the CIMMYT program as parents.

Low average coefficients of infection may indicate the presence of broadly based resistance, and analyses of patterns of reaction to diseases at many sites with different virulence factor combinations allow lines with distinct resistance genes to be identified (Table 1). Although the individual genes cannot be identified by this method, it does provide a simple, rapid means of identifying lines with different resistance genes for use in the breeding program.

Recent leaf rust infection pattern analysis (12) has shown that CIMMYT's Siete Cerros multiline components have many leaf rust resistance genes. In 11 crosses, representing 21 advanced line components, pattern analysis based on 30 localities has shown 16 different resistance groups to be present. Thus, these components have at least 16 distinct leaf rust resistance genes. Seedling tests with leaf rust cultures confirmed the presence of at least seven known and three unknown genes.

Although the main aim of the program is to combine genes from many areas, many crosses are made between lines of the same region to meet the needs of specific countries. The most resistant lines from different regions are then intercrossed to improve the resistance base and to provide more widely adapted germ plasm.

CIMMYT considers leaf rust, stem rust, and stripe rust to be most important. However, screening for resistance to other diseases is justified where they are especially common and economically important. At present, *S. tritici, S. nodorum, Erysiphe graminis, Helminthosporium* spp. (syn. *Drechslera* spp.), and barley yellow dwarf virus come into this category.

The International Nursery System. Data from many sites are obtained through the International Nursery System. These international nurseries originate either in Mexico or from regional CIMMYT programs. Figure 3 (in green) shows how they link the various parts of the CIMMYT and national breeding programs.

The principal nursery, which tests lines after several years selection and yield testing, is the International Bread Wheat Screening Nursery (IBWSN). This nursery, now in its 15th year of operation, tests 400–500 of the highest yielding and most disease-resistant lines selected in the Mexico base breeding program. Seed of these lines is distributed to about 240 centers throughout the world (Fig. 5). Data are received from about 36% of the centers and used to calculate average coefficients of infection for specific diseases. The best lines are then cycled back into the CIMMYT base breeding program in Mexico.

There are two disease-screening nurseries which evaluate lines in greater detail. The Regional Disease and Insect Screening Nursery (RDISN) is administered from Cairo, Egypt, in cooperation with the International Center for Agricultural Research in the Dry Areas (ICARDA), while the Latin American Disease and Insect Screening Nursery (VEOLA) is administered from Quito, Ecuador. The lines sown in the RDISN and VEOLA are obtained from national programs in their respective regions (Fig. 3, in green) and are the most disease-resistant and agronomically desirable types from the eastern and western hemispheres. The lines with the most broadly based resistance are available to all cooperating nations for use in their national programs and are also used in the CIMMYT base program (13) (Fig. 3, in yellow and green).

Two nurseries which are important in ensuring the stability of wheat production in their regions are the Regional Disease Trap Nursery (RDTN) and the Latin American Rust Nursery (ELAR). These nurseries aim to detect changes in pathogen virulence as early as possible and so provide early warning to countries of the need to remove newly susceptible cultivars from production and substitute

Table 2. Differences between multilines produced using the CIMMYT approach and the classical approach

CIMMYT approach	Classical approach
Products of three- or four-way crosses	Products of backcrossing
One to many effective genes in each component	Single effective gene in each component
Rapid production of components	Slow and relatively laborious production of components
All components resistant to all rust strains	Specific components susceptible to certain rust strains
Composite is combination of phenotypically similar lines	Components are near-isogenic lines
Heterogeneous for nontarget diseases	Homogeneous for nontarget diseases
Individual components can serve as cultivars	Individual components should not serve as cultivars

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more resistant ones. The nurseries are sown with commercial cultivars, advanced lines being multiplied, isogenic differentials for the three wheat rusts, and some cultivars to test for other diseases (9).

These nurseries are usually sown in areas where there are many different pathogen virulence genes and in representative wheat-growing areas of the region.

The International Spring Wheat Rust Nursery (ISWRN), started over 28 years ago, is administered by the United States Department of Agriculture (USDA) and is another excellent source of disease-resistant germ plasm for CIMMYT and the developing nations (Fig. 3, in red).

Supportive Strategies

Multiline composites. Another way to achieve greater stability of wheat yields is through the development and use of multiline composites. This means of manipulating rust resistance and the methods used by CIMMYT are discussed in greater detail elsewhere (10,12), but Table 2 shows the main differences between the current CIMMYT approach to producing multiline composites and the classical approach. The CIMMYT approach is considered more practical and useful, especially as it suits the needs of the LDCs.

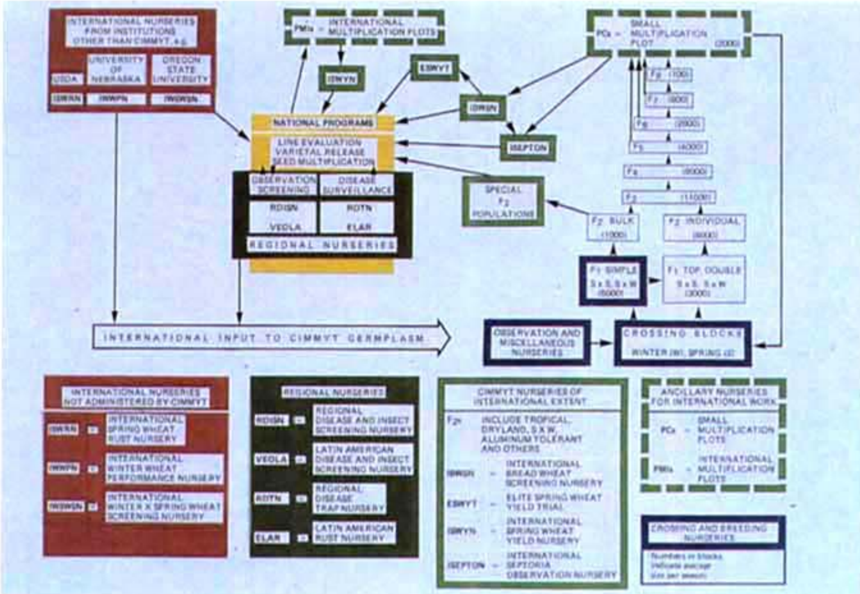

Fig. 3. International flow of wheat germ plasm. CIMMYT manages breeding nurseries (blue) to select advanced lines; its System of International Nurseries (green framed boxes) distributes lines to national programs (yellow). Other institutions (red) provide additional germ plasm resources to national programs. CIMMYT regional nurseries (green) stir up germ plasm movement. Ultimately, national programs may release new high-yielding varieties best adapted to their conditions. Excelling lines will cycle back to the CIMMYT breeding program.

Fig. 4. CIMMYT handles a very great amount of wheat germ plasm with ample diversity for numerous plant characters. Large numbers of advanced lines enable breeders to identify best combinations. Selection and multiplication plots in the winter cycle are planted in the heart of the Yaqui Valley, Sonora, a major agricultural region of Mexico. CIMMYT plots are in the foreground, with CIANO, a regional research station of the National Institute of Agricultural Research, in the center. CIANO hosts CIMMYT operations during the winter cycle.

CIMMYT's responsibility is to *produce* the components for a multiline, and over the last 8 years more than 500 cultivars or lines have been used in top or double crosses with the cultivar Siete Cerros to produce components of the 8156 multiline. It is the responsibility of the pathologists and breeders in each country to *evaluate* and *select* the most useful lines for their own areas.

In 1978 a multiline composite (Bithoor) was released in India. It consists of nine 8156 components bred at CIMMYT but selected in India. This is the first multiline derived from 8156 to be released.

Identification and utilization of slow rusting or dilatory resistance. Dilatory resistance (1), which in relation to rusts is commonly known as slow rusting (2), is distinct from the classical, well-understood, and long-utilized hypersensitive type of resistance. Slow rusting has been little used in wheat breeding programs, but at CIMMYT we hope to identify and use this form of resistance together with pyramided hypersensitive resistance to prolong the usefulness of cultivars. However, it should not be assumed that dilatory resistance is invariably race-nonspecific or horizontal, and much more research is needed to evaluate its nature properly (8).

At CIMMYT, a simple procedure is used to identify lines apparently having this type of resistance to leaf rust. Any of the 1,500–2,000 advanced lines that yields well but is susceptible to leaf rust is selected, and uredospores of the compatible rust are collected and multiplied. These lines are then tested using methods similar to those of Wilcoxon et al (15), and those lines that consistently exhibit slow rusting are used in the crossing program. In F_2 populations, plants with rust reactions less than 10S may also be retained (Fig. 6).

Torim 73 is a slow rusting cultivar grown widely in the Yaqui Valley, Sonora, Mexico. Although it is susceptible to several races of leaf rust that were epidemic on the cultivar Jupateco 73 in this region during 1976–1977, fields of the cultivar Torim 73 rarely suffered any significant yield loss even when inoculum levels were very high. Torim 73 has been widely grown for more than 5 years, and the resistance continues to be effective.

Incorporation of alien resistance. A small effort is made to incorporate alien resistance genes already in wheat

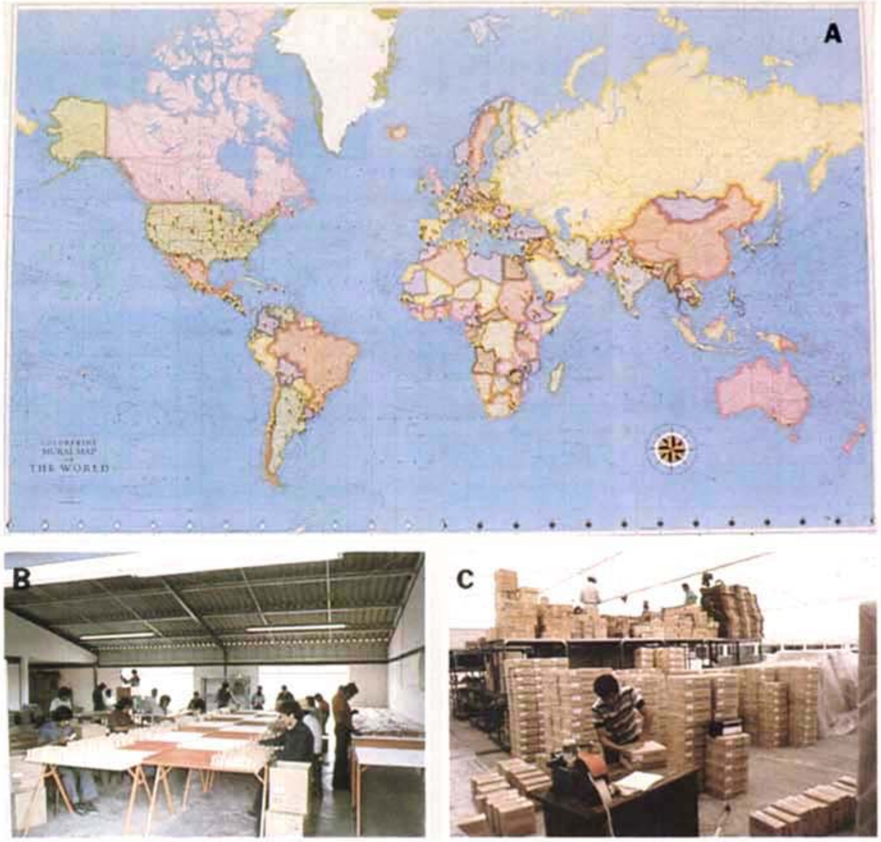

Fig. 5. Multilocation testing has been a major feature of the CIMMYT breeding program. In 1979, 2,276 nurseries were shipped to 115 countries around the world (A). Preparation and shipment of these nurseries involve a large, careful organization (B and C).

Fig. 6. Disease assessment in breeders' nurseries is a major responsibility of CIMMYT wheat pathologists. Young plant scientists from developing nations are trained in Mexico by CIMMYT staff to perform as partners in the collective work of producing new varieties.

backgrounds into the CIMMYT resistance gene pool. Lines containing these genes are crossed with susceptible, high-yielding, well-adapted cultivars in backcross programs, using the latter as the recurrent parents. When the progeny are stable, the best ones are used in the normal double cross program.

Conclusions

The best way in which CIMMYT can provide the LDCs with high-yielding wheat lines adapted to a wide range of conditions and with resistance to many pathogen races is through a large double cross breeding program, associated with multilocation testing. This is CIMMYT's principal strategy, but multilines, dilatory resistance, and alien genes are also used to augment resistance. It is essential that there is a free flow of germ plasm among countries if these aims are to be achieved (Fig. 3).

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