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PRESENT STATUS OF WHEAT IMPROVEMENT IN CIMMYT

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CIMMYT

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by

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INTRODUCTION

Wheat ranks first among world food crops, measured either by planted area (225 million hectares) or by size of harvest (360 million tonnes) (7). The following table shows the comparison of the most important cereals in 1974.

Wheat	360 million tonnes
Paddy rice	323
Maize	293
Barley	171
Sorghum	47

The center of origin for wheat was in the Mideast, near the meeting point of the national boundaries for USSR, Turkey, Iraq and Iran. Wheat and barley were first domesticated in this vicinity. They were carried by early man to the outer reaches of the Eurasian continent, and later by European explorers to all the continents except Antarctica.

More than 70 years of research has brought the average yield of wheat to 2100 kg/ha in industrialized countries compared to 1100 kg/ha in developing countries where research and its application are relatively new. However, a doubling and tripling of wheat yields have been achieved in Mexico, India and Pakistan, and substantial improvement has been made in Turkey and Tunisia. Similar achievements will follow in many other developing countries.

The phrase "green revolution" was coined to describe these spectacular advances in production. Strategies and factors responsible for these advances made in wheat production have been described by Norman E. Borlaug (3,4,5). He pioneered the currently practised wheat breeding methodology at CIMMYT, which has resulted in the release of many widely adapted, high-yielding, fertilizer-responsive, light-insensitive, and rust-resistant semidwarf wheats in various National Programs. These wheats when given proper agronomic practices, were primarily responsible for the "green revolution" in many developing countries. Because of these achievements Borlaug is called the Father of the Green Revolution.

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R.G. Anderson, an early collaborator of Borlaug in India, was largely responsible for catalysing the production breakthrough there and for organizing one of the largest wheat programs in the world. In recent publications (1,2), Anderson discussed the ways and means of further extending the research and technology in the developing world. It is a great honor for me to come to Korea to present the philosophy of wheat breeding research at CIMMYT and to discuss with you some of the problems facing wheat research in Korea and Taiwan.

SHORT PROGRAM HISTORY IN MEXICO

Norman E. Borlaug arrived in Mexico in 1944 as crop pathologist for the Office of Special Studies (a cooperative program between the Mexican Ministry of Agriculture and the Rockefeller Foundation). In those days stem rust was the most devastating disease of wheat, causing periodic epidemics which were national disasters. Mexico was importing half its wheat requirements. Within five years, Borlaug and his Mexican colleagues had developed several new varieties of bread wheat which carried substantially better stem rust resistance than had ever been seen in Mexico before. By 1956 Mexico was self sufficient in wheat. At about the same time attempts were made to incorporate the semidwarf characteristics into the stem rust resistant wheats. In 1962 the first semidwarf wheat was released in Mexico; it almost doubled the yield potential. Since then the wheat program has been producing only semidwarf wheats. By 1973, these semidwarf wheat varieties gave Sonora's Yaqui Valley one of the highest average yields per hectare in the world.

SPREAD OF THE SEMIDWARF GERM PLASM IN THE WORLD

Since 1964, CIMMYT's International Nurseries Program has provided the means by which Mexican wheat germ plasm has been distributed around the world. The semidwarf wheats are presently cultivated on more than 20 million hectares in the developing countries (6). This means that about 10.8 percent of the wheat area is in these high yielding, semidwarf varieties. However, this figure does not include the area sown to semidwarf wheats in USA (California, Arizona and New Mexico), Soviet Union and China (6).

The percentage area sown to semidwarf wheats is relatively small but their impact, especially in developing countries, has been very large because of their higher yield per unit area. CIMMYT believes that the philosophies and methods of its wheat program can contribute substantially towards increasing the spread and impact of the semidwarf, high yielding wheat varieties in developing countries.

OBJECTIVES AND PHILOSOPHY OF THE BREEDING PROGRAM

We at CIMMYT believe that it is not possible to breed cultivars individually adapted to every microenvironment where wheat is grown. Thus our breeding methodology seeks to produce widely adapted wheat germ plasm. To do this, a combination of the following characteristics is needed:

1) High yield potential under many conditions of growth.

2) Semidwarf characteristics.

3) Disease resistance.

4) Daylength insensitivity.

In order to produce cultivars that have wide adaptability and disease resistance we use the following approach.

1) Selection in segregating generation materials at two locations in Mexico for disease resistance and agronomic types.

This practice was developed in the late 1940's by N.E. Borlaug. He pioneered, on an extensive basis, the growing of two generations of wheat materials per year. This is accomplished by growing the segregating populations during the winter in Sonora, Mexico (27°N) at sea level and under irrigated, desert conditions where leaf and stem rusts are endemic.

A second generation is obtained by planting during mid-May at Toluca, Mexico (2,600m), at 19°N. The Toluca site is characterized by heavy rainfall and cool temperatures throughout the growing season. Consequently, severe epidemics of stripe rust develop every year. This procedure halves the time necessary to breed new cultivars; moreover, selection in alternate segregating generations under completely contrasting environments (where a genotype must succeed under both conditions if it is to survive), leads to types capable of adapting to widely differing conditions. Borlaug found that resultant wheat lines were photoperiod insensitive, or possessed a considerable degree of insensitivity because of alternate selection under short day conditions and the resulting wheats could be grown successfully from Alaska to the tropics, under both irrigated and rainfed conditions.

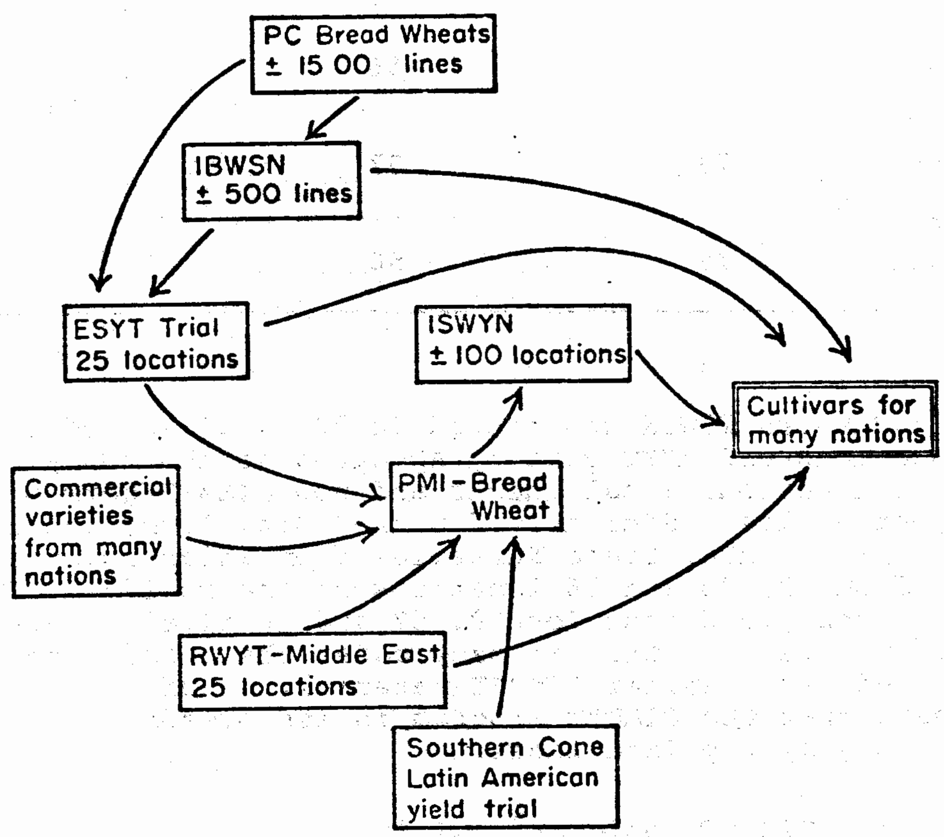
2) International Testing Program helps incorporate genetic diversity in the CIMMYT Wheat Program

Since 1964, The International Spring Wheat Yield Nursery (ISWYN) has provided the vehicle by which the most widely adapted and highest yield potential genotypes available in different countries may be identified. Presently these widely adapted cultivars, together with materials selected from other CIMMYT and National Program Nurseries, are used in the CIMMYT Crossing Program. This allows us to take advantage of more than a decade of world wide observations and provides a dynamic basis for incorporating the best germ plasm into CIMMYT materials.

Genetic research has established that a wheat cultivar tested in many locations, and showing a low coefficient of infection to a disease, often carries a large number of resistance genes. Among the international testing programs that help to identify polygenetically resistant parents are: CIMMYT's International Spring Wheat Yield Nursery (ISWYN), the USDA International Spring Wheat Rust Nursery (ISWRN), CIMMYT's International Bread Wheat Screening Nursery (IBWSN), Near East Regional Disease and Insect Screening Nursery (RDISN) and

CIMMYT's Latin American Disease and Insect Screening Nursery (LADISN). These trials serve several purposes: They signal changes in pathogen virulence and they identify varieties with a broad resistance which can be added to the crossing program. This is predicated on the principle that a cultivar showing resistance in many parts of the world is probably resistant to many virulence factors. Hence, such varieties are likely to carry general or non-specific resistance. The cooperation of many national programs in testing these materials is of the utmost importance. CIMMYT benefits through the identification of genotypes of great value in crosses designed for many national programs. National programs collectively assist one another in obtaining information on varieties to be crossed and which of their individual varietal entries, are most likely to be useful over an extended period of time. These nurseries form a vehicle for widespread distribution of potential varieties or germ plasm as shown in Chart 1.

CHART I. Flow of germ plasm between National and CIMMYT Programs



PC = Small plot multiplication for pure seed

ESYT = Elite Selection Yield Trial (International)

RWYT = Regional Wheat Yield Trial - Middle East

ISWYN = International Spring Wheat Yield Nursery

PMI = International Multiplication Plot

Using these two broad approaches, CIMMYT has achieved spectacular results: Only two cases will be discussed.

1. CIMMYT's International Spring Wheat Yield Nursery has demonstrated that germ plasm developed at CIMMYT or originating elsewhere, utilizing CIMMYT materials, shows superiority in yield performance in most spring wheat growing areas of the world as shown in Table 1.

TABLE 1. Superior cultivars and varieties in World Wide Testing

Nursery	No. of test locations in the world	No. of times CIMMYT germ plasm appears as highest yielder	No. of time local checks and non-CIMMYT varieties appear as highest yielder
(1972-73) 9th ISWYN	70	54	16
(1973-74) 10th ISWYN	72	50	22
(1974-75) 11th ISWYN	73	57	16
(1975-76) 12th ISWYN	76	56	20

The 9th ISWYN was tested in 70 locations of the world and at 54 locations a CIMMYT variety appeared as the top yielder, while at only 16 locations local checks and non CIMMYT germ plasm produced the highest yields. Similarly for the 10th, 11th, and 12th International Spring Wheat Yield Nurseries from which reports have been received from 72, 73 and 76 locations of the world, a CIMMYT variety was in the top yield position 50, 57 and 56 times, respectively. It should be pointed out that in many cases the local check used was also derived from earlier CIMMYT material. Such a performance strongly suggests that the CIMMYT Program in its present approach is proceeding along appropriate lines.

2. CIMMYT semidwarf cultivars have levels of resistance superior to either land races or locally improved, tall cultivars as shown in Table 2. The data are summarized by zones that are assumed to be epidemiologically dissimilar and measured by the average coefficient of infection. The coefficient of infection in the Regional Trap Nursery (RTN) indicates that the local indigenous wheats are all in danger of infection by all 3 rusts in most regions. The improved tall wheats are also susceptible to attack by the three rusts in a similar fashion. The semidwarf wheats on the other hand, are relatively resistant in most locations except in the Indian sub continent, where leaf rust is still a threat.

TABLE 2:

A comparison of the average coefficient of rust infection among local, improved tall and dwarf wheat varieties in four geographical regions for the three year period 1972-1974.*

Variety Group**	Asian Subcontinent	Middle East	North Africa	South Europe	Average
A. Stem rust					
Local	22.35	22.16	15.94	18.67	20.41
Improved tall	8.94	13.19	11.32	11.53	11.57
Dwarf	1.13	4.30	2.95	2.95	3.12
B. Stripe rust					
Local	23.67	18.28	14.61	10.73	15.97
Improved tall	8.07	9.46	5.24	8.23	8.39
Dwarf	4.20	6.39	2.37	2.79	5.62
C. Leaf rust					
Local	36.92	17.34	29.80	21.70	26.11
Improved tall	27.79	14.74	18.40	12.03	18.84
Dwarf	6.32	8.17	5.00	2.33	8.35

* Source: J.M. Prescott, CIMMYT Plant Pathologist, Ankara, Turkey Personal communication.

** Data based on:

1972 7 local, 12 improved tall, 12 dwarf wheats
1973 7 local, 31 improved tall, 14 dwarf wheats
1974 7 local, 21 improved tall, 15 dwarf wheats

It is also evident from the data in the table that one criticism often directed toward CIMMYT material, is false viz: these materials endanger production because, while themselves susceptible, they replace strongly resistant local varieties. The data shows this to be totally false. Such views should be discredited.

YIELD AND STABILITY

As stated earlier, the yield potential of wheat has more than doubled in Mexico (Table 3). The tall variety Yaqui 50, released in 1950, gave a maximum yield of 3.5 t/ha, while the semidwarf releases of the late sixties and seventies have yield potentials of more than 7 tonnes/ha. It is not uncommon for a farmer in Mexico's Yaqui Valley, to obtain a seven tonne yield per hectare when he fertilizes optimally, irrigates well and keeps weeds under control.

TABLE 3:

Yield potential of wheat cultivars bred by CIMMYT or predecessors and released by Mexico for selected years 1950-76.

Cultivar name and year of release	Yield potential* (t/ha)	Plant height (cm)
Yaqui 50	3.50	120
Pitic 62	5.40	100
Sonora 64	5.60	85
Siete Cerros 66	7.00	100
Yecora 70	7.00	75
Jupateco 73	7.50	95
Nacozari 76	7.50	90

* Measured at experiment stations in Mexico

Some of these top yielding varieties in Mexico have given parallel yield performance in many parts of the world. Such varieties as Siete Cerros, Anza, Jupateco 73, Tanori 71, and the recently released Nacozari 76 are examples.

More than 30,000 crosses have been made in the last 6 years to increase rust resistance, incorporate Septoria resistance and improve the yield potential. Considerable success has been obtained in increasing disease resistance, but it has not been possible to materially exceed the yield potential of currently available varieties. It is suggested that a plateauing of yield may be approaching in Yaqui Valley conditions unless further diversified gene pools are used in the crossing program. This is further illustrated in Table 4 where the average performance of the best yielding varieties at each location of the 6th, 7th, 8th, 9th, 10th, 11th and 12th International Spring Wheat Yield Nursery (ISWYN) are summarized. A substantial increase in the performance of the best yielding varieties in the 7th ISWYN over the 6th ISWYN is apparent, but yields have changed little since then even, though a wide spectrum of new semi-dwarfs have been included in recent ISWYN's. This suggests that, while progress can be made in disease resistance, a breakthrough in yield potential has not occurred and will not come easily. However, it should be emphasized that the yield potential of the best available wheats for many regions of the world is satisfactorily high. The major problem now is how to preserve those high yields.

TABLE 4:

Average yield of the top yielding varieties for each location of 6th, 7th, 8th, 9th, 10th, 11th and 12th International Spring Wheat Yield Nursery.

ISWYN	Year	No. of Locations	Av. yield kg/ha
6th	1969-70	60	4329
7th	1970-71	66	5083
8th	1971-72	81	5097
9th	1972-73	71	5233
10th	1973-74	72	5048
11th	1974-75	67	5223
12th	1975-76	76	5294

Devastating disease epidemics can make wheat cultivation nearly impossible and bring hunger and economic instability. The 1967 Septoria epidemic in Morocco, the 1972 Septoria epidemic in Brazil, the 1975 barley yellow dwarf virus epidemic in Chile, the 1960 stem rust epidemic in Brazil and the 1977 leaf rust epidemic in Mexico are recent examples. These epidemics captured national and international attention, and brought severe economic strain to the respective nations.

CIMMYT is well aware of the problem and inherent danger involved in growing similar wheat varieties over large areas of a region. Therefore, considerable emphasis is being placed on the multiline approach as proposed by Borlaug (4) and others many years ago. A proposed method of producing a multiline variety in the CIMMYT Program utilizing the Siete Cerros genotype was discussed earlier (8). This group of varieties representing Siete Cerros has the prerequisite of very wide adaptation and inherent resistance to such diseases as powdery mildew and the smuts. In the last 6 years many components resembling Siete Cerros have been produced, utilizing a double cross breeding system. Multiline composites of Siete Cerros are being yield tested in Mexico and India (Dr. M.V. Rao and co-workers are engaged in evaluating Siete Cerros composites utilizing components produced in India and at CIMMYT). In Mexico the yield performance of some of the best multiline composites are superior to Siete Cerros when tested in areas with severe leaf rust and stripe rust. It is CIMMYT's strong belief that the multiline is a rational approach to minimizing the danger of epidemics and as a result , to stabilizing yield. With this conviction CIMMYT plans to produce multiline composites in such other widely adapted high yielding varieties as Anza, Jupateco 73, Inia 66 and Nacozari 76.

SPRING X WINTER WHEAT CROSSING PROGRAM

Presently, CIMMYT is attempting to raise yield potentials by crossing spring wheats with winter wheats. By intercrossing these two gene pools we may bring complementary factors together which may be expected to lead to yield increases in both the spring and winter wheats. For the spring wheat it is anticipated that the winter germ plasm will enhance yield, drought resistance, and provide additional sources of resistance to septoria leaf spots, powdery mildew, stripe rust and leaf rust. For the winter wheats, the spring wheat germ plasm may increase the yield potential of the winter wheats and provide a range in maturity which can be utilized in different areas. For both types of wheat, the hybridization between them may provide a wide spectrum of variability which has never before been fully exploited.

This program is conducted in collaboration with Oregon State University, Corvallis, Oregon. CIMMYT, utilizing primarily the Toluca research station where winter wheats are vernalized naturally, makes about 1500 spring x winter crosses annually. The F_1 seed is divided equally between the CIMMYT Spring Wheat Program and the Oregon State University Winter Wheat Program. The F_1's are double crosses to spring F_1's in the CIMMYT Program and they are top and double crossed to winter wheats in the Oregon Program. This dual program allows for exploitation of the basic germ plasm for improvement of both spring and winter wheats.

The progenies from these crosses are grown and selected at two sites, Toluca and Cd. Obregón, Mexico, for spring types and at three sites, Hyslop, Moro, and Pendleton, Oregon for winter types. The Mexico sites are varied in altitude and latitude with differing diseases. The Oregon sites differ in rainfall distribution and also in disease patterns. This provides an opportunity to select for wide adaptability in both groups. The resulting advanced lines in the spring program are channeled through the International Bread Wheat Screening Nursery to spring wheat areas of the world. In the same way, the winter types derived from S x W crosses selected in Oregon are distributed to winter wheat areas of the world through the International Winter x Spring Wheat Screening Nursery.

Preliminary evidence indicates that an increase in the yield potential is obtainable from these crosses. In Oregon, advanced winter wheat lines derived from S x W crosses have shown a substantial yield advantage over the best varieties grown there. Similarly spring wheat advanced lines from similar crosses in Mexico are showing the same or better yield performance when compared with the best varieties grown in Mexico.

FUTURE PROSPECTS

CIMMYT is convinced that its present system for breeding and handling segregating populations is the best available, given CIMMYT's purposes. It is also believed that a continuous release of new varieties is needed in order that they may replace old varieties when the latter become epidemiologically vulnerable. Rust and Septoria resistance will remain prime objectives of CIMMYT's crossing and selection program. Multilocation testing for disease resistance remains CIMMYT's basic approach in the selection of parental material. Slow rusting, a possible type of generalized resistance is being incorporated into the program.

CIMMYT will expand the research on multiline composite varieties in regard to epidemiology, resistance, yield potential, adaptation, and quality. Because of the conviction that yield stability can be achieved by preventing disease epidemics, many more high yielding, widely adapted varieties will be chosen by CIMMYT as the agronomic base for new multiline varieties.

It is anticipated that significant additional gains for bread wheats will come in the next few years, each affecting areas with particular problems in growing wheat. These problems include resistance to *Septoria* (significant in Mediterranean countries, in East Africa, and South America), tolerance to aluminum toxicity (especially in acid soils), greater drought and cold tolerance (from spring x winter wheat crosses), and adaptation to hot and humid tropical climates. Advances in each of these problem areas will provide continuing increments to world wheat production.

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