Research Highlights of the CIMMYT Wheat Program

1999-2000

CIMMYT®

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of the
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CIMMYT®
INTERNATIONAL MAIZE AND WHEAT IMPROVEMENT CENTER

CIMMYT® (www.cimmyt.org) is an internationally funded, nonprofit, scientific research and training organization. Headquartered in Mexico, CIMMYT works with agricultural research institutions worldwide to improve the productivity, profitability, and sustainability of maize and wheat systems for poor farmers in developing countries. It is one of 16 food and environmental organizations known as the Future Harvest Centers. Located around the world, the Future Harvest Centers conduct research in partnership with farmers, scientists, and policymakers to help alleviate poverty and increase food security while protecting natural resources. The centers are supported by the Consultative Group on International Agricultural Research (CGIAR) (www.cgiar.org), whose members include nearly 60 countries, private foundations, and regional and international organizations. Financial support for CIMMYT's research agenda also comes from many other sources, including foundations, development banks, and public and private agencies.

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Preface

This volume presents the latest results from a global research program that continues to be one of the most successful of all time. Throughout the developing world, food prices are lower and malnutrition has declined, partly because of the strong research commitment that is reflected in these pages. That commitment remains strong, because the need for wheat research remains great.

In developing countries, demand for wheat will rise by 1.58% per year over the coming two decades, faster than projected growth in demand for rice. By 2020 developing countries will consume 67% of the world's wheat, and wheat will constitute more than 50% of the developing world's net cereal imports. More people will need more locally produced food. At the same time, the agricultural resource base must be strengthened and protected, cropping strategies must be developed to accommodate the potential effects of climate change, and rural communities as well as research organizations must be empowered to meet the challenges of a global economy.

This is no small task, even for a proven research program that is known to be effective from the global level to the fields of individual farmers. The pages that follow indicate the breadth of scientific inquiry that makes the CIMMYT Wheat Program so tremendously responsive to the global, regional, and local needs of partners and those it seeks to help. The reader will find research directed at wheats of different types and growth habits; at the special regional needs of Africa, Central Asia, South Asia, and Latin America; at favored, marginal, and high rainfall environments; at applications of wheat physiology research for breeding strategies; at tillage and mulching practices for a range of needs; at reinforcing disease resistance through molecular and conventional breeding—and this is only a partial list of the contents of this volume!

These *Highlights* demonstrate the power of agricultural research to help the world's marginalized people. The CIMMYT Wheat Program is to be congratulated on this summary of its recent advances and on the scientific leadership and partnerships that have made them possible. In this regard it has been the breadth and richness of our partnerships that have been the cornerstone of global success, and we honor all of our colleagues around the world through these *Highlights*.

Timothy G. Reeves

Director General, CIMMYT

Foreword

We are pleased to initiate this series of publications highlighting research undertaken by the CIMMYT Wheat Program. The purpose of the series is to provide a brief but encompassing look at the Program and to enrich CIMMYT's institutional memory. Since research does not necessarily yield reportable results every year, these highlights will be published every other year.

The Wheat Program harks back to a research initiative that started in the 1940s, before CIMMYT was founded. The key to its continued success over nearly 60 years has been to remain open to change and adapt to new situations. Although it has evolved continuously in terms of its priorities and methodologies, and the clients it serves, through it all, the Program has been true to its core mission: to help wheat farmers in the developing world produce more on less land while protecting natural resources.

The scope of the Program is both global and regional. Our plant breeding programs have achieved global coverage, and we deliver our research products through a network of programs in each region where we work. We could not fulfill our mission without the collaboration of national agriculture research systems throughout the developing world. Through its outreach staff, the Program is present in each of the major regions where wheat is produced: West Asia/North Africa, Central, Eastern, and Southern Africa, South Asia, China, the Andean Region and Southern Cone of South America, and the republics of Central Asia and the Caucasus.

To flesh out the record of activities with more definitive results, we have included a list of publications (book chapters, journal articles, presentations, and abstracts) produced by Wheat Program staff and the roster of CIMMYT-derived varieties released in countries all over the globe in 1999-2000. These products are a direct reflection of the success of our Program, and we are proud to display them.

We hope this document will prove valuable both within and outside of CIMMYT, today and in the future.

Sanjaya Rajaram
Director, CIMMYT Wheat Program

New Conservation Tillage Technologies for Surface-Irrigated Production Systems

K.D. Sayre

Conservation tillage technologies, especially those characterized by zero or very minimum tillage with crop residue retention, have been largely restricted to rainfed production systems, larger-scale farmers, and developed countries.[1] Furthermore, adoption of conservation tillage in irrigated production systems has been extremely limited in both developed and developing countries, except for some small areas where sprinkle irrigation is used.

Vast gravity- or surface-irrigated areas account for well over 50% of wheat area and production in the developing world (China, India, Pakistan, Bangladesh, the Central Asian Republics, Turkey, Egypt, Sudan, Nigeria, and Mexico, among others). However, there had been essentially no development of appropriate reduced or zero-tillage technologies that could be easily implemented by farmers, large or small, in those areas until the recent advances made by CIMMYT agronomists in collaboration with their national agricultural research program colleagues. These advances have occurred mainly in the irrigated rice-wheat systems of South Asia and in the irrigated wheat-maize or soybean system of northwestern Mexico.

Zero-Till Planting of Wheat after Rice under Irrigation in South Asia

In Pakistan in the early 1980s, Dr. Peter Hobbs (CIMMYT wheat agronomist then but currently with CIMMYT's Natural Resources Group) began investigating the possibility of planting wheat after flooded, paddy rice using zero-tillage seeding practices. This approach provided opportunities to reduce production costs and minimize—or even reverse—the long-term, detrimental effects on production sustainability of the considerable tillage being used. However, the major immediate advantage to farmers was the dramatic reduction in crop turn-around time (harvest today, plant tomorrow) that zero-till offered compared to conventional tillage. The period normally needed for land preparation after the rice harvest before planting wheat was sometimes as long as three weeks. Since wheat yields can be reduced by up to 50 kg/ha/day for each day past the optimum planting date, timely wheat planting provides an immediate benefit to farmers.

Since there was no zero-till planter available that was appropriate to the predominantly small-scale Pakistani farmers, Hobbs and his colleagues initially modified a small, zero-till planter imported from New Zealand; it was appropriate in size, but too costly to import and sell commercially in South Asia. The modified, imported planters were used to conduct numerous research trials in farmers' fields in many Pakistani locations over several years. These trials quickly demonstrated the multiple advantages of zero-till wheat planting.

A local machine company began to manufacture a reasonably priced zero-till planter based on the modified planter. However, largely because of skeptics unfamiliar with the technology, nothing happened for another 15 years.

A similar situation occurred in northwest India. Agricultural engineers at Pantanagar University were able to modify the existing "rabi" wheat drill using the same "inverted T" openers introduced by

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[1] The exceptions are Brazil and Argentina, where tremendous progress in adoption of zero-tillage has occurred.

Hobbs on the zero-till planters from New Zealand. The modified planter worked well and was remarkably low priced. But largely due to researcher/leadership skepticism, nothing happened for several years, as occurred in Pakistan.

Several factors were essential for effecting change in both countries, but perhaps most important were two dynamic NARS scientists, Dr. R.K. Malik, weed scientist at HAU in Haryana, India, and Dr. Mustaq Gill, director of the on-farm water management program in the Punjab, Pakistan. Both shared Hobbs' conviction that new, more efficient, economical, and sustainable technologies were needed for the rice-wheat system. They viewed zero-till wheat planting and direct farmer participation as fundamental to developing relevant technologies and getting them out to farmers quickly. They both developed the approach of placing zero till planters in the villages with motivated staff to work with farmers.

The similarity of what occurred in both cases is striking. From a total of about 20 ha planted in a number of farmers' fields two or three years ago, each program planted nearly 6,400 ha of zero-till wheat during the 1999/00 crop cycle. Tremendous farmer demand exists for zero-till planters in both countries, and manufacturers are striving to meet demand. At least 500 planters will be sold in Pakistan this year.

Many farmers now realize that zero-till wheat after paddy rice is a new, integral part of normal production technology for the irrigated paddy rice-wheat cropping system. In addition to higher, more stable yields from more timely wheat planting, farmers are saving about 98 liters of diesel fuel per hectare by reducing the number of tillage passes (up to 10) normally used to plant wheat after flooded paddy rice. Irrigation water savings average nearly 20%, and many annual weeds such as *Phalaris minor* appear to be less prolific under zero-till. The potential effects of this technology are revolutionary, for it offers real progress towards making farmers' production systems more sustainable, input efficient, and profitable.

The events in the province of Punjab in Pakistan and the state of Haryana in India constitute a clear lesson on how to more efficiently introduce new, relevant technologies to small-scale farmers. The technologies need to address real problems and must be tested and understood by the people who will be directly involved with farmers. Researchers should strive for direct farmer participation as early as feasible, i.e., even during the development stage of the technology. Furthermore, when major changes are being made in farmer practices such as converting to zero-till planting, appropriate machinery and equipment, new or modified, will be needed. Someone needs to make sure that the proper prototypes are developed and that some entity will be able to build adequate numbers of good quality machines.

Irrigated Bed Planting Systems in Northwest Mexico

Irrigating crops through furrows or corrugations is not a new technology. It is practiced in parts of West Asia (Turkey and Iran), in Pakistan and China, and is one of the more common irrigation systems in western USA. This irrigation system is more commonly used for row crops such as maize, cotton, dry beans, and soybeans but is also used for small grains such as wheat. Small grains are generally planted on the flat with the irrigation furrows 70-100 cm apart.

Far more common (especially among small farmers in South Asia and China) is irrigated wheat planted on the flat with flood irrigation, though the same farmers may grow other crops with furrow irrigation. Almost all surface-irrigated systems combine heavy tillage with crop residue incorporation (maybe the minority) or crop residue removal, often by burning (probably the majority). Flood irrigation for wheat is practiced on essentially all the irrigated rice-wheat area (about 25 million ha). However, there is at least that much area or more under surface irrigated production systems where wheat is grown in rotation with other crops besides rice.

Given these circumstances, the changes that have occurred in farmers' production practices over the past 25 years in northwest Mexico, especially in the Yaqui Valley of Sonora, have given scientists and farmers the opportunity to develop more sustainable irrigated production systems. This is also an example of farmers taking the lead in modifying production practices, well ahead of most researchers and machinery manufacturers.

Twenty-five to thirty years ago, nearly all farmers in the Yaqui Valley planted their wheat on the flat and used flood irrigation. The wheat production system was characterized by extensive tillage and crop residue burning and by heavy dependence on herbicides to control weeds. Today more than 95% of farmers plant their wheat on beds and use furrow irrigation (70-100 cm between furrows). The major innovation that farmers introduced was to plant on top of each bed 2-3 defined rows, spaced 15-40 cm apart, depending on bed width and row number. This simple modification offered new wheat management options that allowed farmers to dramatically improve production efficiency and reduce production costs. By simply changing to furrow irrigation, they realized an average savings of 25% in irrigation water. By planting 2 or 3 defined rows on top of each bed, farmers were able to gain new advantages for wheat by utilizing management practices such as:

- Pre-seeding irrigation, which allowed the weed population to be controlled mechanically at planting and enhanced crop establishment, especially in heavy, crust-forming soils.
- Mechanical weeding in the furrows and between the rows after crop emergence; this, combined with pre-seeding irrigation, has reduced herbicide use from 70-80% of farmers 25 years ago to less than 10% at present.
- Band application of fertilizers in the bed at planting, followed by banding of side-dress nitrogen at critical times after crop emergence (instead of the more inefficient N broadcast application or application in the irrigation water), which can dramatically improve N use efficiency and enhance grain quality.
- Decreasing intra-plant competition and using lower seed rates, which reduces crop lodging.

The clear advantages of planting wheat on beds made it likely to be useful in other similar areas, especially where irrigated wheat is grown in rotation with other upland crops or with rice. Basic to its dissemination was a training program initiated in 1994 to bring visiting scientists to CIMMYT-Mexico. During the wheat crop cycle in Ciudad Obregon (located in the Yaqui Valley), these scientists study the bed planting system so they can later test its utility in their home areas. Since 1994, over 39 agronomists, mainly from Asia, but also from Africa and Latin America, have been trained in bed planting. Research, development, and extension programs for bed planting are currently underway in India, Pakistan, China, Iran, Turkey, Sudan, and several Central Asian republics. In most cases, similar improvements in production efficiency are being obtained, including irrigation water savings of 25-50%. Although the lack of adequate bed planting machinery has been a common constraint, each country is working on developing appropriate machines.

In the summer of 2000, trials were initiated in India to investigate the feasibility of growing rice on beds in rotation with wheat (R. Gupta, pers. comm.). Some extremely favorable results were obtained, including more than 50% savings in irrigation water compared to transplanted puddled rice. Grain yields were similar in both systems.

Nearly all farmers in the Yaqui Valley continue to use fairly extensive tillage and considerable crop residue burning. However, farmers using the bed planting system have quickly realized that if the same bed width is used for all crops in their production system, they can reduce tillage by reusing the same bed for succeeding crops. Therefore, it is common practice to till, make new beds, and plant wheat. After the wheat harvest, the straw is removed for fodder or burned (most common), and the same beds are then used to plant soybean. After the soybean harvest, tillage is performed again, before planting wheat or another crop.

Burning is practiced due to a lack of planters that can plant soybean into maize residue. Also, no commercial planter is designed to plant 2-3 rows of wheat on top of a bed into residue and without tillage. However, with the bed system, a dramatically reduced till, residue-managed wheat production system for surface irrigated situations could be developed.

In 1993, this author initiated research in the Yaqui Valley to develop a permanent bed system for irrigated wheat-maize and soybean rotation. Here tillage is reduced to a simple reshaping of the beds after harvesting one crop and before planting the next. Residues are chopped and evenly distributed. Much time and effort have gone into developing appropriate machinery to reshape and plant on permanent beds, and very sound prototypes have been developed.

Trials comparing permanent beds and different straw management regimes with conventional-till beds have been conducted for eight years. Results from these trials indicate that crops planted on permanent beds are higher yielding (especially when all residues are retained) than those sown using the conventional farmers' practice, and that the new technology reduces production costs by nearly 25%. Therefore the technology is currently being extended to farmers in northwest Mexico, and scientists from other countries are being trained to disseminate it to other similar areas.

Permanent beds provide the first real opportunity to reduce tillage and retain residues, which leads to marked improvements in soil physical, chemical, and biological parameters and water use efficiency (especially in hot weather) due to the mulch effect. With permanent beds there is better field access to band fertilizers when and where needed, allowing fertilizers (especially N) to be managed more efficiently. Permanent beds also provide a built-in system to control traffic and reduce soil compaction, since all machines circulate on the bottom of the furrows, not on the bed top where crops grow.

Given all its benefits and advantages, the permanent bed planting system is in keeping with CIMMYT's mandate to offer sound, productive, sustainable cropping systems to developing world farmers.

Advances in Mulch-based Conservation Agriculture

P.C. Wall

Over the past two decades there has been a remarkable spread of a new type of agriculture based on residue retention (mulch) and direct seeding into this residue with little soil movement. There are many names for this type of agriculture (no-tillage, zero tillage, direct seeding, and, occasionally, conservation tillage), all of which try to convey the two basic requirements of the system: residue cover and seeding into residue without soil inversion and as little soil movement as possible. Today there are over 50 million hectares under zero-tillage in the world, up from only a few hundred hectares at the beginning of the 1980s. This zero-tillage revolution has required scientists and farmers to rethink and redefine many conventional theories and wisdom on crop and soil management.

The major benefits of residue retention and direct seeding are increased water infiltration (usually leading to higher water use efficiency), a reduction in soil erosion, build-up of soil organic matter, carbon sequestration, and improved soil chemical, physical, and biological fertility. The major benefits to the farmer are the reduction in soil erosion, increased yields (especially in dry years), more timely sowing, less use of manual labor, and large reductions in machinery and fuel costs.

The major characteristic of successful no-tillage systems is the maintenance of sufficient mulch on the soil surface, for mulch is the motor behind the chief benefits of the system. As some pathogens that cause crop diseases are able to survive on the residues, crop rotation becomes even more important in no-tillage systems than it is in conventionally tilled systems. In designing crop rotations, balancing residue production with economic production is important to maintain sufficient soil cover for the system to work.

One of the major reasons for tilling the soil is for weed control; in systems where the soil is not tilled, controlling weeds becomes critical. Initially weeds are controlled by desiccating herbicides prior to seeding, and then with normal post-emergence herbicides. With time, however, in well-managed systems where weeds are not allowed to set seed, weed populations are reduced as seed is no longer incorporated into the soil, the soil seed bank produced by previous conventional tillage is reduced, and the mulch soil cover helps control the weeds. However, good integrated weed control remains a prerequisite for successful systems.

Dissemination of Zero-Tillage Agriculture

Mulch-based conservation agriculture has been adapted to a wide variety of soil, topographical, and climatic conditions. There are areas of no-tillage agriculture from the equator to 50º north latitude and nearly to 40º south. No-tillage is practiced on soils ranging from heavy clays (80% clay fraction in Brazil) to light sands, and on plains and hillsides. The key to this wide adaptation has been the understanding by farmers and scientists of the principles of conservation agriculture and the creative adaptation of equipment and farming systems to overcome practical problems. However, as yet, the system has not worked well in soils with a severe drainage impediment, or where rainfall is too low for annual cropping and residue production is very low.

To date most of the expansion in zero-tillage area has been on large mechanized farms in the USA (19.75 million ha), Brazil (12 million ha), Argentina (8 million ha), Canada (4.08 million ha), Australia (8.64 million ha), Paraguay (0.8 million ha), Mexico

(0.64 million ha), and Bolivia (0.2 million ha) (data from Derpsch, 2000[1]). However, zero-tillage is increasingly being adapted to small farmer circumstances and adopted by small farmers; in Brazil, Mexico, and Paraguay part of the area of expansion is on small farms. There have also been important levels of adoption on small farms in Pakistan, and 100,000 small farmers in Ghana are in the process of adopting this technology (J. Ekboir, pers. comm.).

Major Benefits of Zero-Tillage

In surveys conducted in Brazil and Paraguay, small farmers who have adopted zero-tillage indicated that the main benefit they reaped from the change is the savings in time and manual labor. This has given them more leisure time, allowed them to diversify into other enterprises, and reduced the time children must spend working on the farm (freeing them for more formal education).

A case study in Paraguay[2] showed that average net farm income of the five farms studied doubled (a 101.4% increase), and income for each person-day worked increased by 127%, leading the consultant who conducted the study to conclude that "no-till and crop rotations constitute a technological revolution for small farmers. Never before has the senior author analysed such an impressive technology for small farmers in more than twenty years of extensive experience analysing small farm systems in South America, Africa and Asia. To the authors' knowledge, no other farming techniques have been shown to have such a high impact on farmers' incomes, reduce their production costs and risks, and at the same time be environmentally sustainable and generate very considerable net social gains to society. To realise these private and social benefits will be a major challenge that will call for considerable effort and dedicated support."

Major Restrictions to Adoption

Apart from lack of knowledge of the zero-tillage system, there have been, and still are, two major limitations to zero-tillage adoption on small farms: lack of adequate seeding equipment and other uses of crop residues, principally for animal feed, building, and fuel.

Seeding equipment for large grained crops such as maize is not a major problem: the pointed stick or "punzon" used by many farmers in Mexico and Central America to make the hole for the seed is well adapted to situations with residue cover and, therefore, to zero tillage. This system of seeding is centuries old, as evidenced by a 1549 report by Bishop Diego de Landa that the Mayans in Yucatan, Mexico, were using it. Unfortunately, weed control was also a problem in this system, so prior to seeding, all plant residues on the fields were burned, leaving the soil surface bare. Today many farmers in the same region sow a relay crop of mucuna (a legume) in the maize, which covers the area after the maize harvest. Before the next season it is killed by frost or by a desiccant, and the following maize crop is seeded into the residue. This produces major benefits such as increased fertility following the legume, increased water use efficiency, and excellent weed control due to the ground cover.

Zero-Till Seeding

Much of the zero-tillage seeding of maize and beans on small farms in Brazil is carried out manually with a modern version of the "punzon,"or "matraca." This is a device with two handles that is pushed into the soil; seed and fertilizer are released by bringing together the handles.

Row seeding of crops using machines adapted to animal or human traction has, however, been more problematic, since machines for zero-tillage need to

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[1] Derpsch, R. 2000. Expansión mundial de la siembra directa y avances tecnológicos. Trabajo presentado en el Curso de Siembra Directa, PROCISUR, Cochabamba, Bolivia. 2 al 4 de Mayo del 2000.

[2] Sorrenson, W.J., Duarte, C., and López, P.J. 1998. Economics of no-till compared to conventional cultivation systems on small farms in Paraguay. Policy and investment implications. Final Report of a Study for the Soil Conservation Project MAG-GTZ, DIA/DEAG, Asunción, Paraguay. 228 pp.

be heavier and more rugged to cut through surface residues and penetrate the soil to the required seeding depth. Whereas surface soil in a conventional system is loose and easy to penetrate with a light machine, the surface layer in untilled fields is denser and requires more force for penetration.

Successful machines for widely spaced crops such as maize have been developed in several areas, notably in Brazil. Traditionally these machines have been heavy, a factor that is not normally a problem while seeding, but their maneuverability at field edges is difficult. A new generation of machines relies more on fulcrum physics than on sheer weight, and there are now lightweight seeders available for seeding row crops.

With respect to seeding equipment, the biggest problem remaining is how to sow small-seeded crops such as wheat, barley, and many green manure cover crops. Although single-row seeders can often sow these crops, the time required for seeding is high due to the closeness of the rows. However, advances are being made, and workable machines, although not perfect, are becoming available in India, Pakistan, Ethiopia, and Bolivia (and probably in other countries).

These machines typically seed three to five rows at a time, and are supported on wheels, at least for turning at the field margins. Weight continues to be a problem as the force needed to cut through residues with a 3-row seeder is three times higher than with a single-row seeder. However, the time saved by using these machines is important. In Bolivia a farmer typically prepares his land twice with a wooden plow before seeding, broadcasts the seed, and then incorporates with another pass of the plow. To plant one hectare, the farmer walks 100 km behind his oxen to prepare the land and cover the seed, and another 2 km to sow it. In contrast, if he direct-seeds a hectare with a 3-row seeder (25 cm between rows), he will walk only a little over 13 km and will achieve a far better plant stand with the row-seeded crop than with the broadcast one.

Problems Yet to Be Solved

Alternative uses of crop residues remain a problem in many areas. However, experience in Bolivia shows that once farmers see the benefits of surface residue retention in their fields, they are far more willing to look for and adopt alternate feed sources. These include sowing forage crops during the normally fallow period and planting of live contour barriers with forage species, which reduce erosion and slowly form terraces. Increased grain and straw yields attained with more efficient water use also allow farmers to use part of the crop residues for feed and still leave enough residues for adequate ground cover on the field. However, one major problem is that according to local custom, grazing rights after harvest are communal, which means that an individual farmer is not allowed to maintain crop residues in his field; rather, this is a community decision.

Another problem facing development agencies is harvest methodology. Hand-harvesting small-grain cereals and then threshing by trampling the crop outside the field means most of the straw is removed from the field. Returning the straw for ground cover is expensive in terms of manpower, and unattractive to farmers. On flat or gently sloping land, machine harvesting is the preferred method, as it is generally cheaper than hand-harvesting, reduces the harvest-to-market interval, results in a cleaner product, and leaves crop residues on the field. However, development efforts are required to make machine harvesting more widely available and to promote small custom-harvesting enterprises.

New Bread Wheats for High Rainfall Environments: The Package

M. van Ginkel and L. Gilchrist

High rainfall environments make up the second major mega-environment where bread wheat is grown in the world, after irrigated production areas. Particularly in developing countries, regions receiving more than 500 mm of rainfall during the cropping cycle suffer retarded economic development and the associated curses of unemployment, poverty, ill health, and high infancy death rates. Such areas include parts of Eastern, Central, and Southern Africa, the Andean Region of South America, China, and pockets in South Asia.

Enormous progress has been achieved in disseminating so-called modern varieties in irrigated regions around the world. Key wheat ideotypes, such as the Veerys and, more recently, the new wheats Kauz and Attila, have demonstrated their wide adaptation and stable performance across this irrigated agro-ecological zone. Adoption of modern wheats has reached almost 100% in high rainfall areas in the last decade. However, few genotypes have shown to contain the complete "package" of requirements for that zone. The Bobwhites constituted an impressive advance some 20 years ago, but with evolving diseases and market demands, new varieties are continuously needed. Usually varieties do well for a certain period and then succumb to diseases, or their quality characteristics remain poor, and local mills import most of the wheat they require, negatively impacting local wheat producers.

There are several reasons for production instability in high rainfall areas. For example, more diseases thrive under higher humidity conditions than in irrigated or rainfed areas with low humidity, and nutrient imbalances (both deficiencies and toxicities) are more pronounced in regions where leaching associated with high rainfall is prevalent.

In many of these areas, wheat has been imported in large amounts, for a variety of reasons, including famines, political mismanagement of food resources, lack of support for agricultural research, immigration/emigration pressures, cost/benefit considerations, and the high industrial quality of imports. Imported wheats generally come from one or more of the top four wheat exporters in the world: USA, Canada, Argentina, and Australia. Since these countries grow wheat mostly under rainfed conditions and produce the low yields (1.5-2.5 t/ha) associated with elevated protein levels, imported wheat is generally of superior quality.

Traits for High Rainfall Wheats

If a nation in a high rainfall area aims to satisfy some, most, or all of its domestic wheat needs, its breeders must address an extensive list of traits. Wheats targeted towards high rainfall areas should have some or, ideally, all of the following key traits:

1. Yield
    a. High*
    b. Stable*
2. Disease resistance
    a. Stripe rust*
    b. Leaf rust*
    c. Stem rust*
    d. *Septoria tritici**
    e. *Fusarium* spp. (head scab)*
    f. Barley yellow dwarf virus
    g. Soil-borne pathogens
    h. Tan spot
    i. Powdery mildew

3. Abiotic stress tolerance
    a. Sprouting*
    b. Soil acidity
    c. Nutrient imbalances*
    d. Waterlogging
4. Industrial quality
    a. Bread making*
    b. Cookie quality
    c. Noodle quality (for China and Southeast Asia)

Though not all these traits are usually present in the same variety, the 10 marked by an asterisk (*) often constitute the minimum requirement in a high rainfall environment, compared to 5-7 key traits needed in wheats targeted to irrigated environments. Breeding wheats that meet these requirements poses a difficult challenge—one that requires concerted efforts to meet it. The difficulty is compounded by the fact that many countries in high rainfall areas have been investing less in wheat research in recent years.

Breeding and Selecting High Rainfall Wheats

Breeding wheats possessing the set of traits required in a given target environment is key to getting local farmers to adopt them. To incorporate the key groups of traits detailed above breeders must apply different methodologies; each group will therefore be discussed separately.

Yield

Traits contributing to high, stable yields across all potential production conditions within the high rainfall mega-environment are not unlike those needed to produce top yields in less stressed conditions under irrigation. Optimum input use efficiencies should result in maximum output (grain yield) per hectare. Hence in the hybridization process of a breeding program targeting high rainfall conditions, the highest yielding genotypes under irrigated conditions should be exploited, i.e., yield genes governing internal physiological processes should be transferred to potential high rainfall wheats. These genes constitute the genetic core of a variety and determine its ultimate yield potential. In addition to the top irrigated wheats, the best yielding high rainfall wheats are also sources of genes for yield.

Table 1 lists some of the highest yielding wheats tested under high rainfall conditions in Mexico, in comparison to the check line Prinia.

In all three crosses listed in Table 1, top-yielding irrigated wheats (Veery #9, Seri M82, and Tui) are present as progenitors and presumably contributed "yield genes." An example of an outstanding high rainfall progenitor is Bobwhite, which in the past two decades has proven to be high yielding and stable in such areas around the world.

Disease resistance

Once the introgression of yield genes into a variety has been secured, their potential must be protected from diseases so that high yields will be phenotypically expressed in farmers' fields. Protective disease resistance genes should be incorporated into the new wheat through the proper choice of additional parents in the crossing process.

Horizontal resistance is pursued against diseases known to have host-pathogen interactions of a specific, race-type nature. Though these diseases are restricted mostly to the rusts, some claim that certain foliar blights also show interactive behavior. Horizontal resistance is also known as adult-plant, partial, or field resistance and, in the case of the rusts, as slow-rusting resistance. This type of resistance is achieved by accumulating several genes, each with minor additive effects. Parents are used in combinations that will yield progenies carrying three or more minor resistance genes for each of the relevant diseases. In the case of the rusts,

Table 1. High yielding lines compared to the check variety Prinia, 2000 crop cycle, Toluca, Mexico.

Cross	Selection history	Yield (t/ha)	Prinia %
PFAU/BOW//VEE#9/3/DUCULA	CMSS95Y02460S-0100Y-0200M-19Y-010M-6Y-030M-2SJ-0Y	10.87	143
PGO/SERI//BAU/3/DUCULA	CMSS95Y02262S-0100Y-0200M-10Y-010M-10Y-030M-2SJ-0Y	10.73	141
MILAN/TUI	CMSS95Y02595S-0100Y-0200M-2Y-010M-5Y-030M-3PZ-0Y	10.36	131

CIMMYT scientists have published on 12 such existing minor genes, but estimates are that many such genes reside in CIMMYT and other germplasm, just waiting to be accumulated. For diseases that do not express large host-pathogen interactions in farmers' fields (mostly foliar blights and soil-borne diseases), major genes with strong effects can be used.

Table 2 lists entries that showed outstanding resistance to *Septoria tritici* during the past crop cycle in the Mexican highlands, where there was a particularly strong epidemic due to very conducive environmental conditions.

The crosses confirm the assumption that more than one of the parents contributed resistance genes to these lines, resulting in pyramided resistance. Likely contributions are from South American sources (IAS58 within TINAMOU), French stocks (VS73.600 within MILAN), a CIMMYT cross released as SARA in Guatemala (within DUCULA), plus several Chinese wheats (NG8675 and CHUANMAI 18 within CATBIRD). Also note that SERI, a high yielding variety mostly for irrigated environments, again transmits adaptation to this group.

Table 2. Lines showing a high level of resistance to *Septoria tritici* during the 2000 crop cycle, Toluca, Mexico.

Cross	Selection history	*Septoria tritici* 00-99*
TNMU/MILAN	CMSS95Y02037S-0100Y-0200M-12Y-010M-4Y-030M-4SJ-0Y	11
PGO/SERI//BAU/3/DUCULA	CMSS95Y02262S-0100Y-0200M-2Y-010M-7Y-030M-3PZ-0Y	11
NG8675/CBRD//MILAN	CMSS95Y02978S-0100Y-0200M-17Y-010M-3Y-030M-0Y	11

* 00-99 is the widely adopted Double-Digit scale.

Table 3. Lines showing they carry accumulated, diverse genes for Type II resistance (reduced spread of fungus through the spike's rachis) to Fusarium head scab, 2000 crop cycle, Toluca, Mexico.

Cross	Selection history	Resistance Type II (%)*
SHA3/CBRD	CMSS92Y00595S-1SCM-0CHN-015Y-3SCM	2.50**
HXL8088/DUCULA	CMSS93Y02492S-2Y-010M-010Y-010M-10Y-1M-0Y-3SJ-0Y	2.59
CROC_1/AE.SQUARROSA (205)//BORL95	CIGM90.250-4Y-3B-4Y-0B-2M-24M-0Y-010SCM-0Y-0Y-0Y	3.41
TNMU/3/JUP/BJY//SARA	CMBW91M02016S-0M-040Y-1AL-2AL-7Y-0M-3SJ-0Y	3.70
KAUZ/TNMU	CMSS93B01069S-54Y-010M-010Y-010M-8Y-0M-3PZ-0Y	5.00
SUMAI#3 (moderately resistant check)		9.20

* Denotes % of spikelets affected per spike.
** This entry also allows only very low toxin levels.

Table 3 presents new lines in which the progenitors of the crosses would suggest that several genes for Fusarium head scab (FHS) resistance were successfully accumulated; this is also indicated by the disease response data (Type II resistance against spread of the disease through the rachis). Research is in progress to determine whether these genes are indeed different from one another and from earlier used genes.

These five examples illustrate several points:

- Germplasm from several regions of China may contribute resistance to Fusarium head scab: Sichuan (CHUANMAI 18 within CATBIRD), Shanghai (SHA #3), and Heilongjiang (HXL8088).
- These Chinese lines may add distinct genes that can be accumulated: SHA3/CBRD is more resistant than either parent.
- Synthetic wheats (e.g., CROC_1/AE.SQUARROSA (205)) do confer resistance. In this particular synthetic the resistance derives from the *Aegilops squarrosa* parent (205) since the durum parent (CROC) is known to be highly susceptible to scab.
- South American wheats (IAS58 within TINAMOU, and the CIMMYT cross released as SARA in Guatemala) bestow resistance genes.
- The Mexican highland sites Patzcuaro (PZ) and Sierra de Jalisco (SJ) assist in identifying resistant materials, as confirmed by their presence in certain selection histories: CMSS93Y02492S-2Y-010M-010Y-010M-10Y-1M-0Y-3SJ-0Y and CMSS93B01069S-54Y-010M-010Y-010M-8Y-0M-3PZ-0Y.
- Resistance to Fusarium head scab can be successfully combined with materials that are principally known for their high yields in irrigated conditions (BORLAUG F 95 and KAUZ).
- Some of these lines also contain tolerance to acid soils, as attested by the "-AL" notation in their selection histories, which indicates that they were subjected to laboratory hydroponic testing using

solutions with high aluminum levels (CMBW91M02016S-0M-040Y-1AL-2AL-7Y-0M-3SJ-0Y).

- Most FHS resistance sources noted also convey maintenance of a low toxin level in the grain despite fungal infection.
- The advanced wheats listed are also resistant to the three common rusts plus *Septoria tritici*.

Abiotic stress tolerance

One of the key abiotic constraints to production in high rainfall areas is the high amount of rain that falls on the maturing wheat crop. Excess rain causes the grain to start germinating before it is harvested, which compromises end-use quality due to the undesirable proteins produced during germination. High rainfall wheats should possess sprouting tolerance to counteract this problem. Intermediate levels of sprouting tolerance are available, mostly in red-grained wheats, but higher levels are being sought. Table 4 lists both red- and white-grained wheat lines combining excellent sprouting tolerance with acceptable yield and industrial quality.

These lines were selected from a Mexico/Australia shuttle breeding effort. In Mexico the planting date was adjusted so that grain-filling would coincide with peak seasonal rainfall in Toluca; this caused sprouting in sensitive segregants. In Australia the populations were exposed to artificial excess moisture in a controlled environment, again permitting identification of desired tolerant genotypes. The sources of sprouting tolerance were Columbus and Sunco/SA1166.

Table 4. Red- and white-grained lines having high levels of sprouting tolerance in combination with acceptable yield (relative to the check variety Prinia) and end-use quality (loaf volume).

Cross	Selection history	Yield Prinia %	Grain color	Loaf volume
TUI/CLMS	N91.358-3WM-102AUS-5WM-010WM-010Y-010M-10Y-0Y	102	Red	1025
HAHN/PRL//CLMS/3/HAHN/PRL	N92.240-2WM-60AUS-2WM-010WM-010Y-010M-2Y-0Y	91	White	875
TUI//2*SUNCO/SA1166/3/TUI	N92.241-1WM-71AUS-6WM-010WM-010Y-010M-9Y-0Y	102	Red	900

Table 5. New lines showing high levels of industrial quality during the 2000 crop cycle (MV-00), Toluca, Mexico.

Cross	Selection history	Use type	W value	P/L	Flour protein
MILAN/TUI	CMSS95Y02595S-0100Y-0200M-2Y-010M-5Y-030M-1PZ-0Y	1a*	785	0.9	12.7
TNMU/MILAN	CMSS95Y02037S-0100Y-0200M-14Y-010M-1Y-030M-1PZ-0Y	1a	660	0.7	12.8
MILAN//PSN/BOW	CMSS95Y02329S-0100Y-0200M-9Y-010M-9Y-030M-3PZ-0Y	1a	536	0.8	12.9

* Use-type 1a = ideal dough strength and extensibility with high protein levels.

Industrial quality

Industrial quality must be a key consideration when choosing parents. If the proper complementary genes are not introduced during hybridization, they cannot be expected to turn up in the progeny. Once the proper genes have been introduced, it has become increasingly evident that not much needs to be done in regard to selection for industrial quality until advanced lines appear. Apparently these genes transmit themselves well through segregating populations, so that a sufficient number of high quality lines will emerge in the F7.

Several lines showed very high levels of industrial quality during the last Toluca crop cycle (Table 5). The quality values of these lines are in fact among the highest one could expect to obtain (W values above 500) while maintaining high protein levels.

The 446 most outstanding lines from the recent ME2 yield trials have been entered into the most recent issue (10th) of the international nursery High Rainfall Wheat Screening Nursery (10th HRWSN). The new entries express high yield as well as resistance to stem, leaf, and stripe rusts, and *Septoria tricici*, plus a certain level of resistance to Fusarium head scab.

Of the 446 entries, 101 (23%) have so-called group 1 quality (balanced, strong, extensible); 76 (17%) of these actually show 1a type quality (balanced, strong, extensible, but with protein levels above 12%), the highest bread making quality level attainable. Such high quality wheat is used mostly for blending purposes (i.e., to correct inferior flour). An additional 67 entries (15%) have group 2 quality, representing good bread making quality.

Taken together these data indicate that 38% of the 10th HRWSN has good to excellent industrial end-use quality. This represents a breakthrough in terms of combining top yield and disease resistance with high levels of industrial quality.

The Package

It is clear from the above data that the key traits required in high rainfall environments are now available in different genotypes. In fact, in several cases yield, resistance, and quality values reveal an accumulation of desired genes for the respective trait.

The final step in the process of breeding wheats for high rainfall environments remains to be taken and will settle the issue of whether the various complexes of accumulated genes can be combined to produce genotypes that would individually express all the key traits.

Recent data have indicated that this is indeed possible. For example, a select sample of elite genotypes grown in the Mexican highlands during the past one or two crop cycles appear to combine high yield with resistance to the rusts and *Septoria tritici*, plus high levels of industrial quality (Table 6).

These entries have not yet been exhaustively evaluated for FHS resistance under controlled conditions using artificial inoculation, nor have they been tested for sprouting tolerance, two of the 10 key traits indicated above. Their pedigrees (combining resistant progenitors) and selection histories (of lines selected in Patzcuaro or Sierra de Jalisco, where scab levels tend to be very high) suggest that they may well possess FHS resistance. In fact a sister line of the first mentioned line, TNMU/MUNIA, has already been confirmed to have a high level of resistance to FHS.

Conclusions

The world depends on breeders to provide farmers with commercially competitive crop varieties that will contribute to the lofty and necessary goal of attaining overall food security. But in practice individual farmers do not consider such lofty goals; instead they make simple though integrated economic decisions that reflect their agronomic production environment and direct relation to the local commodity market. Thus for a farmer a variety must yield well with a high level of predictability, and have the quality that local grain buyers demand. In response, breeders need to construct complex genetic packages (varieties) that satisfy farmers' "simple" requirements.

The traits that ensure a wheat variety will succeed in high rainfall environments are many. In particular these wheats face numerous diseases, which means that the combined resistances needed to protect them can only be obtained through concerted research efforts and may be lost as pathogens evolve. Breeders must also combat climatic and environmental vagaries that impact yield and quality.

Fortunately, as documented in this report, it is nevertheless possible to develop genetic wheat packages for high rainfall environments that rival the best irrigated wheats in yield and that defend themselves successfully against numerous diseases, while producing grain of superior industrial quality.

Table 6. New lines combining high yield (relative to check variety Prinia) with high levels of *Septoria tritici* resistance and good industrial quality characteristics, 2000 crop cycle (MV-00), Toluca, Mexico.

Cross	Selection history	Yield (t/ha)	Prinia %	*Septoria tritici* 00-99	Use-type*	W value**	P/L ***	Flour protein****
TNMU/MUNIA	CMSS93B01052S-18Y-010M-010Y-010M-4Y-3M-0Y-1PZ-0Y	9.06	129	11	1a	595	1.3	11.7
MILAN//PSN/BOW	CMSS95Y02329S-0100Y-0200M-9Y-010M-9Y-030M-4SJ-0Y	9.09	120	21	1a	530	0.5	13.3
ALD/COC//URES/3/DUCULA	CMSS95Y02455S-0100Y-0200M- 10Y-010M-4Y-030M-2PZ-0Y	9.59	126	11	1a	392	1.0	12.2

* Use-type 1a = ideal quality wheat with strong, balanced, extensible dough.

** W value must be 300 or above.

*** P/L ratio must be 0.6-1.0.

**** Flour protein must be near 12% or above.

Breeding Wheat for Marginal Environments

R.M. Trethowan

The Target Environments

The CIMMYT bread wheat program produces germplasm adapted to a wide range of different moisture stress conditions. The breeding work focuses on the following environments, each classified by the stage at which moisture stress generally occurs:

- *Post-anthesis stress*. These areas are characterized by adequate winter rainfall with moisture stress prevalent during grainfilling; an estimated 6 million ha are found in developing countries. North Africa and West Asia are representative areas.
- *Pre-anthesis stress.* These environments suffer from winter drought with generally favorable conditions post-flowering. An estimated 3 million ha are found in developing countries. The Southern Cone of South America is typical of this type of stress.
- *Severe terminal stress*. Farmers in these areas generally plant on stored soil moisture. Little or no rainfall occurs post-planting. The monsoonal areas of South Asia and the spring-wheat-growing lands of Central Asia/Western Siberia are typical. More than 20 million ha with this type of stress are found in developing countries.

Selecting Materials for Crossing

The CIMMYT program targets crosses for all these areas by utilizing the most widely grown cultivars and elite breeding lines from collaborating national programs. These materials are crossed to elite CIMMYT lines with high yield potential, disease resistance, and grain quality. Synthetic hexaploid wheat, produced by crossing durum wheat with *Aegilops squarrosa*, is heavily used in crosses and provides new sources of variation for stress adaptive traits. The resulting progeny are then tested in the various regions via the deployment of elite international yield and screening nurseries. The information collected in the regions on these materials is returned to CIMMYT and used by the breeders to target the next round of crossing. Scientists working in national programs either release these lines directly, reselect them, or recombine them with their own germplasm.

Managing Segregating Populations

At the base program in Mexico, segregating material is selected under alternating conditions of moisture stress and high rainfall with high disease pressure. Drought stress is simulated at CIMMYT's experiment research station near Cuidad Obregon, northwestern Mexico (27ºN, 25 masl) using limited irrigation. The heritability of selection under drought stress from year to year ranges from 0.5 to 0.7. This high degree of repeatability sets Obregon apart from most of the world's rainfed wheat-growing areas. Variable rainfall from year to year makes selection for genuine drought adaptation in these areas extremely difficult, as heritability across years is often close to zero under most rainfed conditions. Each alternate generation is selected under high rainfall and high disease pressure at CIMMYT's Toluca research station (19ºN, 2600 masl) in the central Mexican highlands. This shuttle allows breeders to develop drought tolerant, input responsive germplasm with high levels of disease resistance, which is essential for maintaining yield and income stability for farmers living in marginal areas.

Evaluating Advanced Materials Targeted for International Distribution

Once advanced lines have been identified, they are yield tested at Obregon under two contrasting moisture regimes to identify the drought tolerant, input responsive genotypes. Following three years of yield and disease evaluation, the selected lines enter the CIMMYT international nursery system in one of the three following nurseries:

- SAWYT – Semi Arid Wheat Yield Trial
- SAWSN – Semi Arid Wheat Screening Nursery
- HLWSN – High Latitude Wheat Screening Nursery

Data on the performance of these lines across the target marginal areas are collected by regional cooperators and returned to CIMMYT to aid the selection of parents for the crossing program.

Progress to Date in Breeding for Marginal Areas

Prior to the introduction of the SAWYT in the early 1990s, the national agricultural research programs of most wheat growing developing countries selected materials for their marginal areas from CIMMYT's traditional irrigated nurseries with significant success. A recent examination of the performance of 20 years of the Elite Spring Wheat Yield Trial (ESWYT) indicated that yield improved across this period at close to 4% per year (Pingali, 2000).

All materials entering the ESWYT have been bred and selected under optimally irrigated conditions. However, results from the SAWYT indicate that rates of progress can be improved through the deployment of materials bred and targeted to moisture stress conditions. In low yielding environments (less than 2.5 t/ha), rates of progress, expressed as yield advantage of the best five lines over the local check cultivar, have increased from 12% in 1991 to 38% in 1997 (Figure 1). Similarly, the yield advantage of these top ranking genotypes in environments suffering intermediate levels of stress (2.5-4.5 t/ha) has improved from 16% to 45% over the same time period. The regression of yield advance over time was significant for both low and intermediate yielding environments ($r^2 = 0.62$, $P<0.01$ and $r^2 = 0.42$ $P<0.05$, respectively).

Refining the Breeding Effort for Marginal Areas

There is little doubt that significant progress was made during the past 30 years in developing cultivars suitable to marginal areas. However, the question is: can we improve upon or maintain these rates of progress? This is of vital importance, as many analysts believe improved production in marginal areas is key to food security in the coming decades (P. Pingali, pers. comm.).

The CIMMYT bread, durum, and triticale breeding programs have not been idle in this respect. Experiments have been conducted to evaluate current breeding and evaluation strategies in an attempt to fine-tune the already highly successful breeding effort. An examination of the relationship between the severe terminal stress generated in Obregon and global marginal areas using data generated by the SAWYT indicated that key target areas in South Asia correlated well with Obregon. Although high yielding, adapted germplasm could

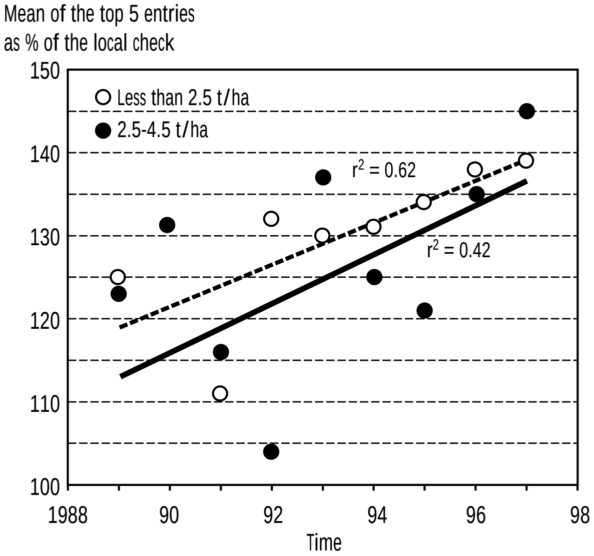

Figure 1. Trends in yield over time in low and intermediate yielding environments.

be selected from either the SAWYT or SAWSN in nearly every environment, not all environments differentiated germplasm in the same way as Obregon. Results indicated that a small adjustment to the timing of drought stress in Obregon could improve the correlated ranking of Obregon with some environments, particularly in the Southern Cone of South America. Combining what we know of global wheat environments on the basis of yield performance with GIS and other environmental variables will help to improve definition of the marginal areas and better target germplasm to CIMMYT's regional cooperators.

Advances in molecular biology are expected to provide exciting opportunities to improve the efficiency of wheat breeding for marginal areas. Functional genomics in particular may provide the knowledge needed to enhance parental selection and identify gene clusters important in conferring adaptation to stress. Genomics will likely be a more powerful tool than QTL analysis, as drought tolerance is likely to be controlled by many hundreds, possibly thousands, of gene loci. To complicate matters, these loci "clouds" will change with the environment. As a minimum, DNA fingerprinting of key parental stocks will allow breeders to better design crosses and calculate coefficients of parentage more realistically.

Understanding the Target Environment

The adaptation of germplasm to marginal areas involves much more than just drought tolerance. For one thing, root health often determines a plant's ability to perform well under drought. Root growth can be influenced by a number of biotic and abiotic factors including nematodes, root rots, and micro-nutrient toxicities and deficiencies (Table 1). Many of these traits are simply inherited and can be manipulated to improve general adaptation to marginal areas. Bioassays for root diseases are difficult to manage and escapes are frequent; therefore, molecular markers (if available) offer significant advantages. The CIMMYT Wheat Program routinely uses a PCR assay to determine nematode resistance, and more markers are undergoing validation.

We know that significant genotype x location interaction occurs from the deployment of SAWYT and ESWYT across many environments, yet we do not understand why certain genotypes perform well in one environment and collapse in another. Deployment of a probe set of genotypes, differentiating for the key soil-borne stresses, is planned over the next few years. It is hoped that this trial will shed some light on the major limitations to the adaptation of wheat in many key marginal areas. This knowledge will help breeders at CIMMYT target germplasm to regions. For example, some areas may be prone to root lesion nematode, and more appropriate advanced lines and parental materials could be provided to our partners there. Knowledge of such constraints is a powerful tool in our efforts to achieve increased food production in the coming decades.

As farmers become conscious of the need to conserve soil moisture and reduce erosion (Table 1), farming practices are changing in many wheat growing areas. Wheat breeding programs must be proactive in promoting changes in their selection and evaluation strategies to reflect the changing environment. If research suggests that no genotype x tillage practice interaction exist in a given region,

Table 1. Factors affecting yield in dry environments.

Patterns of moisture stress	Temperature extremes	Nutrient stress and pH extremes	Biotic stress	Agronomic practices
Terminal	Heat stress; humid	P and N deficiency/efficiency	Root rots	Stubble retention
Pre-anthesis	Heat stress; dry	Deficiency (e.g. zinc)	Nematodes	Zero tillage
Residual moisture	Cold stress	Toxicity (e.g. boron)	Foliar pathogens	Crop rotations
Reduced irrigation	Cold stress–late frost	Acid soils, mineral		Shifting cultivation
General low rainfall		Acid soils, volcanic/organic		Water harvesting
Shallow, marginal, infertile, eroded lands		Alkaline soils		

this may simply reflect a lack of variability for key determinants of adaptation to conservation tillage in the genotypes tested. At CIMMYT, all materials targeted to marginal areas are being screened for their ability to emerge and establish from varying sowing depths. Key diseases such as yellow spot and crown rot, which sometimes increase under conservation tillage, are now routinely tested and evaluated. A key objective for the future will be to encourage regional cooperators to move their key yield evaluation trials on farm. One of the limitations of the international yield trial testing network over the years has been the over-representation of experiment research stations in the data returned. Very few trials have been sown under farmer-managed conditions. It will become increasingly important to move these trials on farm, as producers begin to adopt more sustainable farming practices.

Increasing Durum Wheat Yield Potential and Yield Stability

W.H. Pfeiffer, K.D. Sayre, and T.S. Payne

It is estimated that global wheat production must increase by 40% in the next 20 years to meet the rising demand for wheat grain. Increasing production intensity in ecosystems that lend themselves to sustainable intensification while decreasing the intensity in more fragile ecosystems may be the only way for agriculture to keep pace with population (Borlaug and Dowswell, 1997). Based on projections that per capita land and water resources will diminish during the current century, recent studies predict production must increase by 1.6% per annum over the next 20 years to meet the rising demand for wheat on the global level (Byerlee and Traxler, 1999; Calderini et al., 1999). This poses an immense challenge to wheat research teams, given that recent annual production gains have been of a smaller magnitude.

Hence, greater reliance on maximizing production efficiency, or grain yield potential (GYP), under various agroecological scenarios will be required. Environmental, cultural, and political sustainability will define the focus of our research agenda. CIMMYT aims to contribute to this effort by protecting past achievements in yield potential and adaptation through continuing an aggressive program of incorporating resistance to abiotic and biotic stresses. This strategy capitalizes on newer empirical methods, advances in information technology, morphological and physiological markers, a broad genetic resource base, and emerging biotechnologies. To date, high rates of progress in raising GYP have been achieved in spring durum and bread wheats.

Inception of the CIMMYT Durum Wheat Breeding Program

Systematic durum wheat enhancement at CIMMYT in Mexico started in 1965 under the leadership of Dr. Norman E. Borlaug. Early breeding ventures focused on the introgression of dwarfing genes and alleles for photoperiod insensitivity, improvement of floral fertility, and enhanced biotic stress resistance. Interestingly recent publications suggest re-visiting these options (e.g., photoperiod insensitivity). Breeding in Mexico concentrated on agronomic components associated with high genetic yield potential and wide adaptation in combination with quality attributes. The target areas were irrigated, subtropical environments, the areas where the Green Revolution began.

The CIMMYT durum project became international in the late 1960s, once the agronomic problems of the first semidwarfs (e.g., sterility) were solved. Varieties such as Jori 69 and other germplasm products were developed for a wider range of agroecological conditions and were adopted in a number of countries. After spillovers to other agroecological zones became evident in the 1980s—genotypes from traditional durum growing areas were heavily used as progenitors—breeding objectives were expanded to include high rainfall and moisture-stressed environments, with less attention given to GYP improvement *per se*.

The international reach of the durum breeding program is reflected in the adoption of its hallmark cultivars, such as Cocorit 71, Mexicali 75, and Yavaros 79, which are still widely grown in many countries. Yavaros 79, for example, has been released in more than 30 countries under more than 40 names. The next generation of durum varieties, released in the 1980s (e.g., Altar 84 and Aconchi 89) trace back to breeding based on the ideotype concept. Common features are upright leaf characteristics derived from the Shearwater genetic stock and significantly improved end-use quality (yellow pigment and gluten characteristics).

Progress in Raising the Genetic Yield Potential

To gauge historic progress due to breeding, the relative performance of these five cultivars were assessed in maximum yield potential trials (MYPT) conducted at Cd. Obregon, in northwest Mexico. Improvements in grain yield were associated with increased biomass yield (Figure 1), though harvest index decreased. Changes in grain yield were due to increased grains m^{-2} via more grains spike^{-1}. Additionally, rate of grainfill increased, cultivars headed and matured later, and had improved test weights.

Genetic progress in CIMMYT durum germplasm developed during the past decade was investigated by comparing the best performing durum genotypes from the MYPTs. The mean of the five hallmark checks was used for comparison to minimize the effect of individual genotype x environment interactions. These comparisons retrospectively chart changes that have occurred through genotypic improvement suggesting strategies to affect improvement of yield *per se* in the future.

For the past decade, elite germplasm exhibited genetic advances for nearly all the agronomic components (Figures 2 and 3) with the greatest changes observed in grain yield, biomass, and grains m^{-2}. Increases in biomass production rate from crop emergence to physiological maturity and from anthesis to physiological maturity were high. Most recently, increases in both spikes m^{-2} (+8.9%) and grains spike^{-1} (+7.2%) resulted in a dramatic rise of +16.9% for grains m^{-2}. Grain biomass production rate (+16.6%), spike weight (+4.8%), and vegetative growth rate (+4.5%) all increased, while the downward trend in 1000-grain weight (–2.8%) continued. More recent genotypes are later in heading and maturity, with a surprisingly shorter grain-filling period.

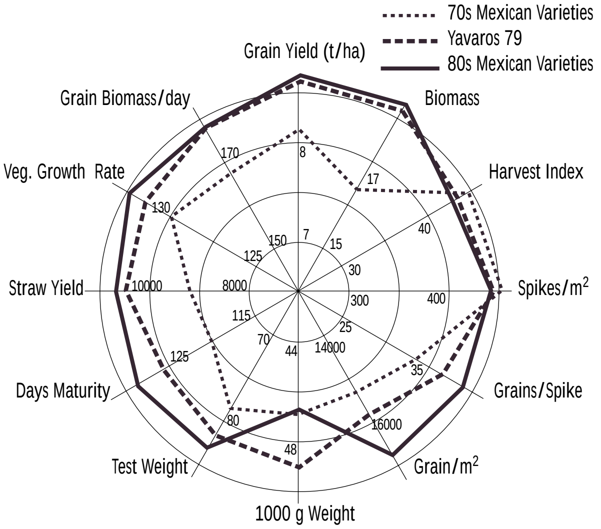

Figure 1. Comparison of agronomic components of the highest yielding early 1970s (Cocorit 71, Mexicali 75), Yavaros 79, and 1980s (Altar 84, Aconchi 89) durum wheat varieties evaluated in maximum yield potential trials at Cd. Obregon 1991-1999.

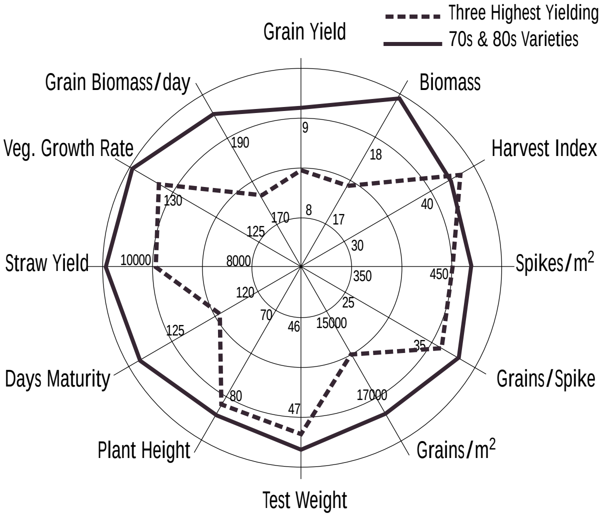

Figure 2. Comparison of agronomic components of the three respective highest yielding durums compared with check varieties (Cocorit 71, Mexicali 75, Yavaros 79, Altar 84, Aconchi 89) evaluated in maximum yield potential trials at Cd. Obregon 1991-1999.

Strategies for Further Improving Yield Potential

"Balancing" yield component architecture and biomass

Contrasting the performance of top yielding durums with top yielding bread wheat genotypes may produce models for identifying alternate avenues to obtaining higher yield for either crop. Pfeiffer et al. (1996) suggested that lower numbers of spikes m^{-2} and grains m^{-2} in durums compared with bread wheat should receive special attention in durum improvement, since past experience indicated superior bread wheat performance was associated with number of spikes m^{-2}. Figure 4 discloses a gradual correction of this delinquency in contemporary durum wheats, revealing a converging of yield architecture in durum and bread wheat.

Earlier efforts to increase biomass focused on manipulating spikes m^{-2} and, later, on augmenting the number of grains spike^{-1}, both of which are traits suitable for phenotypic selection. The avenue of selecting for grains m^{-2} via a higher number of grains spike^{-1} proved superior in raising GYP. Negative effects on spikes m^{-2} were minor and 1000-grain weight could be maintained. Over 1997-99, the simultaneous increase in both spikes m^{-2} and grains spike^{-1} produced the highest increase in grains m^{-2}, GYP, and biomass. The balance in yield components may have approached a near optimal constellation, as results from crop comparison suggest. With limited scope for increasing the partitioning of assimilates to the grain, future progress has to be based on increased biomass.

Exploring physiological strategies to enhance grain yield potential

Physiological strategies that can be applied empirically to accelerate the rate of breeding progress include increase radiation use efficiency (RUE) and, therefore, total plant biomass, increased grain number, and increased kernel weight. These three strategies do not address the issue of how to provide extra assimilates during the spike growth period (i.e., booting) so that higher grain number and grain weight potential can be achieved. Such strategies are discussed in more detail elsewhere (Reynolds et al., 1999; Reynolds et al., 2000). These strategies should be incorporated into analytical and empirical selection approaches.

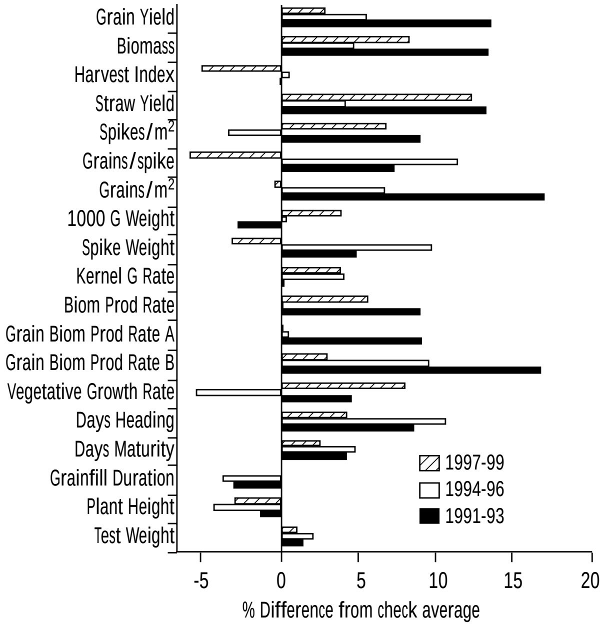

Figure 3. Changes in agronomic components in durum in three time periods: comparison between the respective 3 highest yielding lines and 5 historical checks.
Data source: Agronomy yield trials, 1991-1999.

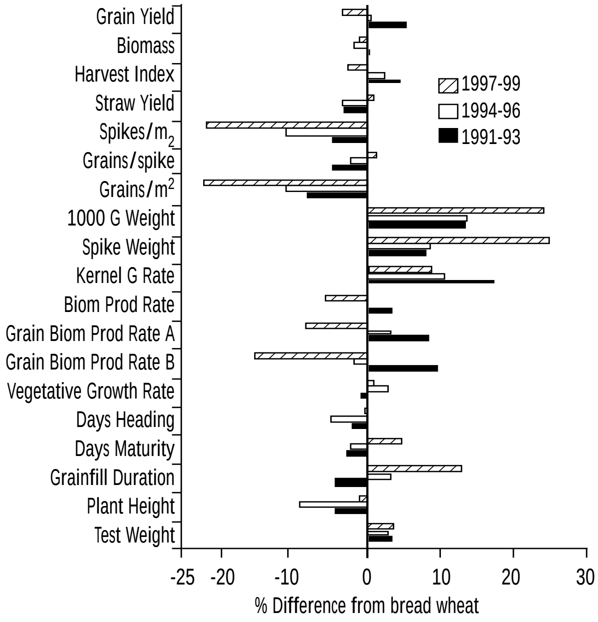

Figure 4. Changes in agronomic components in durum in three time periods: comparison between the respective 3 highest yielding durum and bread wheats.
Data source: Agronomy maximum yield trials, 1991-1999.

Parallel enhancement of yield components, which determine grains m^{-2}, may be recommended to minimize competition among yield factors with overlapping developmental stages. A further expansion of the duration of the reproductive phase or higher growth rates during the different phenological stages should result in higher biomass during this presumably source-limited period.

Determination of individual grain weight is essentially independent of yield components associated with grains m^{-2}. Nevertheless, grains m^{-2} and 1000-grain weight are negatively associated, as the decline in grain weight over time has been over-compensated by an increase in grain number. Several assumptions regarding this relationship have been discussed in the context of sink-source relationship to enhance GYP (Richards 1996; Slafer et al., 1996). Given high trait heritability and the immense genetic variation for 1000-grain weight (with maximum values above 75 mg $grain^{-1}$), improvement of grain size, *ceteris paribus*, is a promising strategy from a breeding perspective to raise yield *per se*. Heterosis for grain size in wheat and triticale hybrids, the primary trait affected, indicates enormous potential supporting a hypothesis that gains can be achieved without sacrificing grains m^{-2}.

Stabilizing improved yield potential

Achievements in improving GYP can be traced to concomitant improvements in raising yield *per se* and increasing yield stability. MYPT data reveal that in years with an overall performance below the long-term average, more recently developed genotypes exhibit greater performance stability than the hallmark checks (Pfeiffer et al., 1996). Superior spatial, temporal, and systems stability can be combined with maximum yield *per se*. However, while current GYP stabilization efforts have emphasized individual buffering of homozygous genotypes, greater consideration should be given to population buffering effects in heterozygous populations and different population structures in future breeding efforts.

Future Challenges

Increased GYP growth rates must match future demands for food. To achieve anticipated production levels, breeding for realized GYP should emphasize enhancement of yield *per se* and GYP stability through integrated, interdisciplinary approaches that take into account environmental sustainability. This challenge requires concerted, complementary efforts to gather a critical mass of scientists and achieve essential operational sizes; sound hypotheses and strategies, translated into breeding objectives; free exchange of germplasm and information; and dynamic cooperation among the global community of scientists. Each one of these requirements must be met if we are to accomplish our common mission: the alleviation of poverty and hunger.

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A New Approach to Triticale Improvement

A.R. Hede

Humankind faces an unprecedented challenge in the next century: the need to more than double the world's food supply in response to rising populations and increased incomes. The global demand for cereals will grow dramatically due two factors: an increase in direct consumption demand for grain, as well as increased demand for animal feed (to satisfy, in turn, a growing demand for meat products). The way forward will be through significantly increasing the yield potential of the world's major crops, and in some cases developing highly productive new crops that fit into specific agricultural niches.

One of the most promising crops in the latter category is triticale (X *Triticosecale* Wittmack), a man-made cross between wheat and rye. Triticale combines many of the best qualities of both its parents: the robustness of rye (adaptability to marginal soils, drought tolerance, winter hardiness, disease resistance, and low input requirements relative to wheat) and wheat's end-use qualities (such as its flavor and suitability for making numerous products for human consumption).

Advantages of the New Triticales

In the last 40 years, triticale has progressed from being an agricultural curiosity to being cultivated on more than 3 million ha worldwide. Two factors have contributed to its popularity: considerable improvements in its yield potential and grain quality, and a growing appreciation of the particular advantages it has over other food and feed crops such as wheat, oats, barley, rye, and ryegrass.

Several types of triticale are now available. Some produce good quality flour for use in cookie, flatbread, and pasta production, and can be mixed with wheat flour for making bread. Other triticales have been developed as dual-purpose (feed and forage) sources for livestock. In preliminary studies, the latter types have been shown to have significantly better nutritional profiles (better amino acid composition, fiber content, palatability, and more metabolizable energy) for animal consumption than conventional grains or forage crops. In the medium term, it appears that one of triticale's competitive niches may be as a feed crop.

Triticale's other niche is an ecological one. It outshines most other cereals under agronomically stressed conditions such as:

- **Drought-prone environments.** Anecdotal evidence suggests that triticale requires approximately **30% less water** to produce the same amount of biomass (grain and forage material) as wheat, sorghum, oats, or ryegrass;
- **Acid soils.** Such soils have a high soluble aluminum content toxic to cereals, and cover more than 100 million ha of potentially arable land. Recent varieties of triticale yield at least 30% more than either wheat or barley on these soils.
- **Sandy (low-nutrient) and saline soils.** Experiments with triticale in sandy soils (e.g., in North Africa) show the crop outyields wheat and barley by approximately 33%. On saline soils, triticale yields some 10% more than bread and durum wheats, but is not quite as productive as barley.
- **Insect- and disease-infested environments.** Triticale has better resistance than wheat and barley to such major insect pests such as Hessian fly (endemic in North Africa) and Russian wheat aphid, as well as better tolerance to plant diseases such as the cereal rusts, barley yellow dwarf, and several foliar diseases.

Taken together, these factors suggest that triticale is an ideal crop for future cultivation in stressed agricultural environments in South America (Argentina, Brazil, and Uruguay, especially on the continent's vast acid soil expanses), North Africa, Kenya, South Africa, and India. It could have particular advantages in countries that are currently importing grains for livestock feed.

Progress in grain yield potential

Since the establishment of the CIMMYT triticale breeding program in 1964, improvement in realized grain yield potential has been remarkable. In 1968, at Ciudad Obregon, Sonora State in northwest Mexico, the highest yielding triticale line produced 2.4 t/ha with a test weight of 65.8 kg/hl. Eleven years later under similar conditions the best triticale line yielded 8.5 t/ha with a test weight of 72 kg/hl. Triticale's yield potential has continued to increase in the subsequent 10 years of breeding at CIMMYT.

Under near optimal conditions at Cd. Obregon, a comparison in maximum-yield trials of triticales developed in the 1980s and 1990s reveals an average yield increase of 1.5%/year. Today's high yielding CIMMYT spring triticale lines (e.g., Pollmer-2) have surpassed the 10 t/ha yield barrier under optimum production conditions at Cd. Obregon. Figure 1 shows the results of a maximum-yield potential trial in which 16 triticale, durum, and bread wheat genotypes were planted in Cd. Obregon during the 1999/2000 cycle.

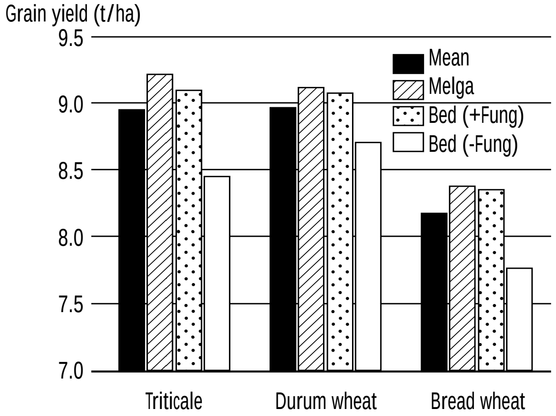

Figure 1. Grain yield potential of triticale, durum wheat, and bread wheat. Mean of 16 genotypes. Cd. Obregon, Mexico, 1999/2000.

Animal feed and forage potential: Better nutritional balance

In response to specific requirements of end-users and markets, substantial emphasis has been placed on developing feed grain, dual-purpose forage/grain, and grazing types of triticale since 1990. Major efforts are being invested in developing facultative and winter habit triticales that will produce higher forage biomass than spring types. Forage-specific cultivars have been released in several countries, where they are being used successfully for forage, silage, grain/forage, or hay.

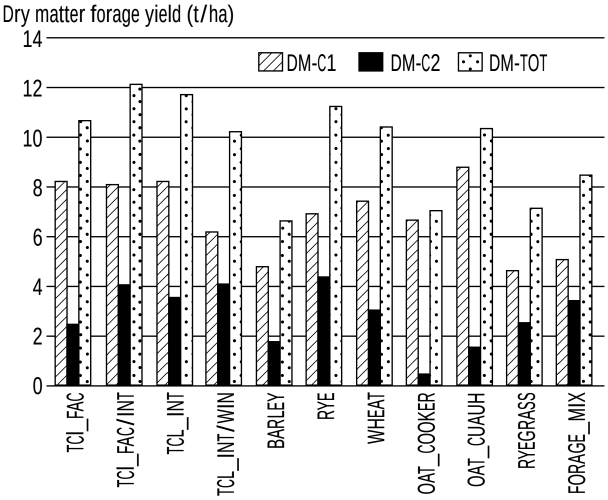

Figure 2. Dry matter (DM) forage yield in two cuts (C1 and C2) and total (TOT) of triticale (TCL) and other cereals at Salaices, Chihuahua, Mexico, 1998/99.

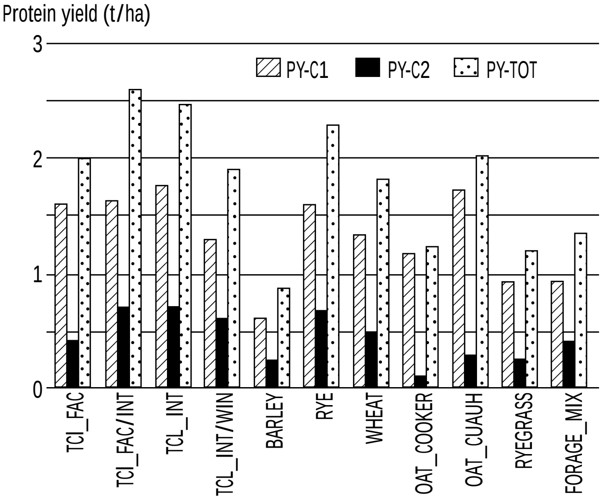

Figure 3. Protein yield (PY) in two cuts (C1 and C2) and total (TOT) of triticale (TCL) and other cereals at Salaices, Chihuahua, Mexico, 1998/99.

CIMMYT triticale lines were evaluated for dry matter production and nutritional value in northern Mexico. Results of these trials demonstrated that winter/facultative triticales significantly outperformed such traditional forage crops as oat and ryegrass. Trials during the 1998/99 crop cycle, in which wheat, rye, and barley were included as checks, produced similar results, with triticale showing higher dry matter yields and better quality than any of the other forage crops (Figures 2-5). Triticale's high forage biomass production and forage quality should increase animal performance, reduce feeding costs, and generate higher returns. In addition, in many countries cereal straw is a major feed source for animals. Under arid and semi-arid conditions, triticale has been shown to consistently produce higher straw yields than wheat and barley.

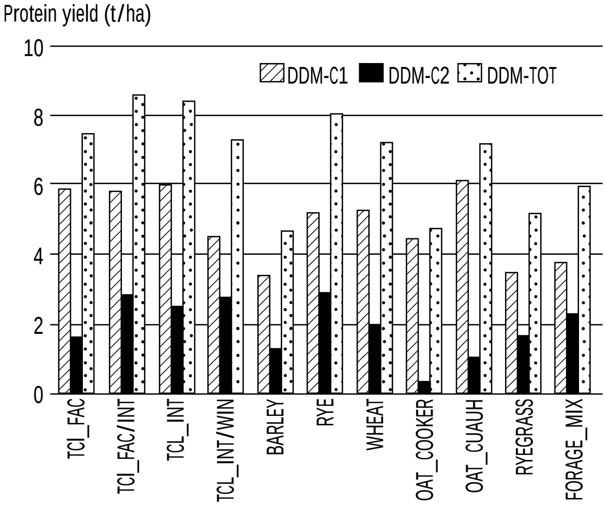

Figure 4. Digestible dry matter (DDM) yield in two cuts (C1 and C2) and total (TOT) of triticale (TCL) and other cereals at Salaices, Chihuahua, Mexico, 1998/99.

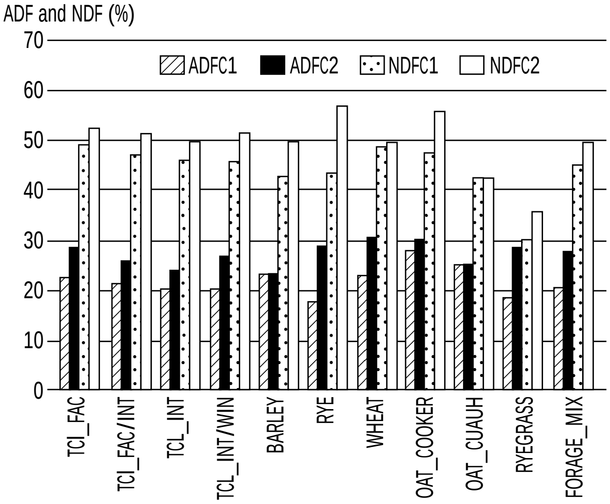

Figure 5. Acid detergent fiber (ADF) and neutral detergent fiber (NDF) in two cuts (C1 and C2) and total (TOT) of triticale (TCL) and other cereals at Salaices, Chihuahua, Mexico, 1998/99.

Triticale has clear advantages as an animal feed. Its amino acid composition fits the nutritional requirements of monogastrics and poultry very well. Studies in Algeria and Tunisia have shown that triticale can substitute for maize (*Zea mays*) in poultry feed rations. In Australia farmers have demonstrated a preference for feeding triticale to cattle (particularly dairy) because of its superior metabolizable energy, palatability, and appropriate fiber content, compared to other grains available (Cooper, pers. comm.). Similarly, the excellence of triticale as a total grain ration for pigs is becoming well known, since, unlike other grains tested, it does not interact negatively with legumes in the diet. Thus, in the future chemical analysis (e.g., crude protein and metabolizable energy) of promising triticale lines will become a routine component of varietal screening at CIMMYT, as a means of identifying genotypes with desirable nutritional profiles.

Hybrid Triticale

Given the dramatic demand for food, feed, and fodder in 21st century and the commercial success of other hybrid crops, the use of hybrid triticales as a strategy for sustainably enhancing grain and forage production in favorable as well as marginal environments is promising. Triticale displays the pollination control traits required for hybrid seed production: excellent anther extrusion, large anther size and an associated large amount of pollen, and excellent cross pollination capacity.

Furthermore, in many countries distribution of non pedigreed seed from farm to farm reduces the return on investment to the cultivar developer, which diminishes the incentive to conduct crop research, and in the end, reduces the dissemination of improved seed and new technologies to farmers. This problem would be reduced with hybrid triticale. In hybrids maximum levels of heterosis are expressed in the F1 hybrid, so in order to achieve maximum yields, pedigreed seed would have to be purchased every year.

Chemical hybridizing agent (CHA) hybrids

Early research at CIMMYT on triticale hybrids aimed at evaluating heterosis for agronomic traits in hexaploid triticale hybrids produced using a chemical hybridizing agent. Thirty-one hybrids from 3 male and 15 female elite hexaploid spring triticales were produced by CHA. All triticales used were complete R-genome types, except one 2D(2R) chromosome substituted type, which was used as a male parent. Male parents were selected based on performance under high production conditions. Female parents were selected based on performance in different agro-ecological zones and for their contrasting yield component expression. Yield trials including CHA hybrids and parents were conducted under high production conditions in Cd. Obregon during the 1995-96 and 1996-97 growing cycles to evaluate grain yield and agronomic traits.

A combined analysis of 1995-96 and 1996-97 data revealed, on average, 9.5% mid-parent and 5.2% high parent heterosis for grain yield. Maximum heterosis values greater than 20% were observed for grain yield in high-parent (22.9%), mid-parent (24.9%), and low parent (28.9%) comparisons.

Mid-parent heterosis for agronomic components were observed in: biomass (9.1%), straw yield (9.0%), 1000 grain weight (11.4%), culm weight (12.0%), and spike weight (12.4%). This differential contribution of yield components to grain yield heterosis could be exploited in designing hybrids. Several hybrids revealed superior biomass performance and would be preferred for forage utilization, e.g. whole crop silage production.

Cytoplasmic male sterility (CMS) hybrids

Several alien cytoplasms, such as *Triticum timopheevi* Zhuk., *Aegilops sharonensis*, *Aegilops juvenalis*, *Aegilops heldreichi* and *Aegilops ovata* cytoplasm, cause male sterility in wheat and triticale. *Triticum timopheevi* Zhuk. cytoplasm has been used in different countries to produce commercial bread wheat hybrids. In wheat, fertility restoration genes from *Triticum timopheevi* Zhuk. have been introduced and are employed along with modifier genes for fertility restoration. In contrast to wheat, most triticales carry fertility restoration genes on the R genome.

In 1994, CIMMYT started a small applied research project on hexaploid spring CMS triticale hybrids based on *T. timopheevi* Zhuk. cytoplasm. In the first phase, elite CIMMYT spring triticales were crossed onto a CMS source to identify non-restoring lines (potential females in CMS hybrids) and lines carrying restorer genes (potential males). Out of 25 genotypes that exhibited complete or partial sterility in the F1 hybrid generation (CMS source x tester line), 18 lines were retained as potential CMS recipients and subsequently backcrossed. After four backcrosses, 300 test hybrids were produced during the 1997 El Batan crop cycle from 15 CMS lines and 27 male lines. The restoration capacity of the elite triticales used as males had been determined in the F1 hybrid generation. Two hundred CMS hybrids and their parents were tested under high production conditions at Cd. Obregon during the 1997-98 growing cycle to evaluate grain yield.

Analysis of 1997-98 data revealed, on average, 9.1% mid-parent and 3.3% high parent heterosis for grain yield. Heterosis values for grain yield in mid-parent comparisons were: 29 hybrids: 1-5%, 34 hybrids: 6-10%, 41 hybrids: 11-15%, 31 hybrids: 16-20%, 17 hybrids: 21-30%, and 3 hybrids: more than 30% with a maximum of 48%. Heterosis values for grain yield for high-parent comparisons were: 42 hybrids: 1-5%, 35 hybrids: 6-10%, 28 hybrids: 11-15%, 11 hybrids: 16-20%, 1 hybrid: 21-30%, and 3 hybrids: more than 30% with a maximum of 44%.

Average grain yield of the experiment was 7.22 t/ ha. CMS hybrid grain yields varied from 9.48 t/ha to 5.86 t/ha and averaged 7.32 t/ha. Grain yields for parents ranged from 8.26 t/ha to 5.32 t/ha and averaged 6.81 t/ha. Results indicate that high absolute grain yields were due to high heterosis. Grain yield of the top yielding CMS hybrid compared with the top yielding parent was +15%.

The CIMMYT triticale program continues to emphasize the identification of new superior hybrid combinations, and during the 1998-99 crop cycle, more than 500 new hybrid combinations were made. These were evaluated for agronomic traits and disease resistance in two environments, and the superior 120 hybrid combinations were planted in replicated yield trials under optimal and drought conditions at Cd. Obregon during the 1999-2000 growing cycle. The experiments demonstrated that there is no clear relationship between high parent heterosis under irrigated and drought conditions, although a few hybrids demonstrated high levels of heterosis under both types of conditions (Figure 6). High parent heterosis levels of the best hybrids were between 10-20%, and these superior triticale hybrids outyielded the check cultivar (Pollmer 2) by up to 20% (Figure 7).

Possible impacts of hybrid triticale

High heterosis for value-added traits suggests the feasibility of developing commercial triticale hybrids with substantial gains in genetic grain and forage yield potential, given the existing genetic variation. Hybrids can be successfully designed from inferior yielding parents carrying special attributes (for example, for disease resistance), involving fewer adapted alien sources to exploit potentials of marginal environments, or unique end-use quality traits. High heterosis in hybrids involving 2D(2R) substitution types suggests the presence of contrasting heterotic groups between the complete R and substituted 2D(2R) genepools and/or heterotic effects from D genome chromosomes. As with most commercial hybrid crops, an increase in heterosis can be anticipated along with the identification of heterotic genepools and directed breeding efforts for hybrid progenitors.

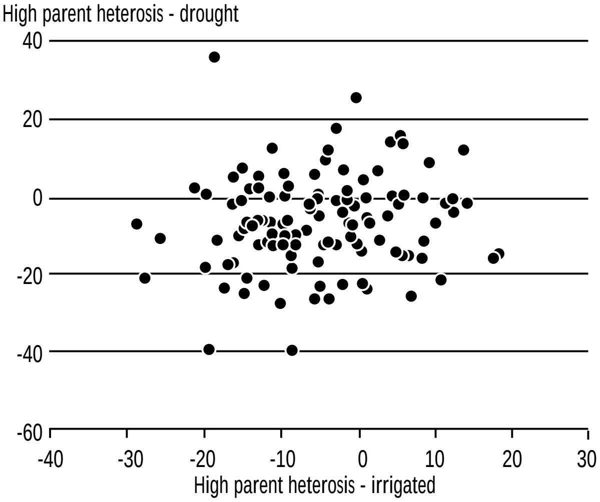

Figure 6. Relationship between high parent heterosis under irrigated and drought conditions, Cd. Obregon, Mexico, 1999/2000.

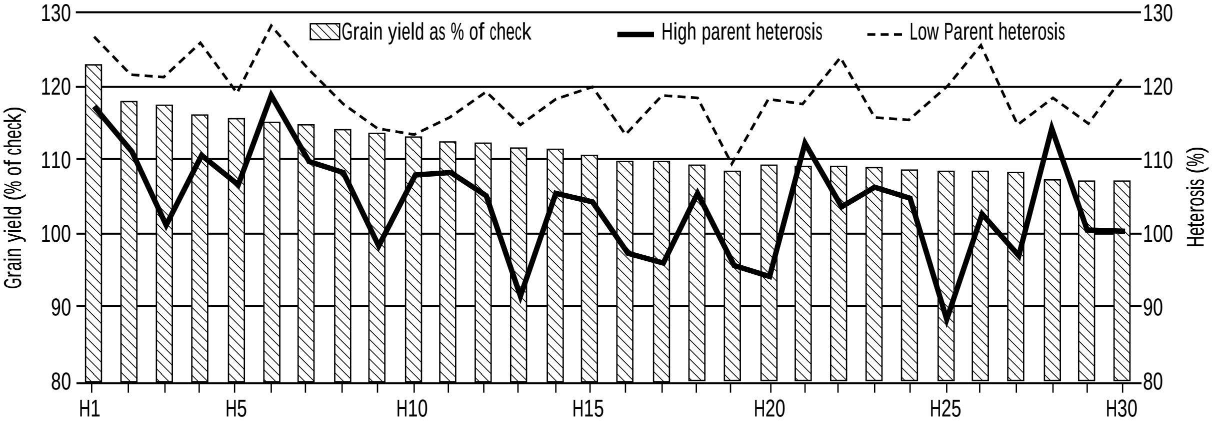

Figure 7. Grain yield as % of check (Pollmer 2) and high and low parent heterosis of selected triticale hybrids, under irrigation, Cd. Obregon, Mexico, 1999/2000.

The high cost of hybrid seed is one of the major limiting factors for the commercialization of hybrid wheat. Experience at CIMMYT shows that for triticale, costs of hybrid seed production are substantially lower when compared with wheat due to high, close-to-normal seed set in hybrid production plots. Furthermore, fewer male pollinator rows need to be planted. CMS hybrids show clear advantages over CHA hybrids in terms of seed production costs. Production of CHA hybrids does involve substantial costs due to determining the dosis of the gametocide, monitoring seed production fields to optimize the application of the chemical hybridizing agent, gametocide product costs, and royalties for the gametocide. Furthermore, male pollinators can be blended with CMS females and planted as mixture for hybrid seed production to further reduce costs. This practice is common in hybrid rye production in Europe.

Lack of uniformity in CMS hybrids and a certain percentage of the male in hybrid seed are likely irrelevant, e.g., for forage and grazing hybrids. Moreover, forage/grazing CMS hybrids do not require fertility restoration in the hybrid; hence, hybrid development is less complicated and costly. On the other hand, the costs of developing CMS hybrids are much higher than for developing CHA hybrids, and crop improvement is complicated and requires a considerable amount of resources. Molecular markers for restorer/non-restorer genes could dramatically reduce the cost of developing CMS hybrids (> 75%).

Adaptation of Winter Wheat to Central and West Asia

H.-J. Braun,[1] M. Mergoum,[1] A. Morgounov,[2] and J. Nicol[3]

Winter and facultative wheats are grown on an estimated 43 million ha in Central and West Asia (CWANA), Central and Eastern Europe (CEE), and Russia. Wheat acreage of the mega-environments (ME), as defined by CIMMYT, is for winter wheat: ME 10 (irrigated) 1.5 million ha, ME 11 (high rainfall) 25 million ha and ME 12 (rainfed) 7 million ha. Facultative wheat area in ME 7 (irrigated) is 2.8 million ha, ME 8 (high rainfall) 1.35 million ha and ME 9 (rainfed) 5.5 million ha. Around 65% of the winter and facultative wheat area in Central Asia and the Caucasus is irrigated, compared to 20% in West Asia and North Africa.

The Turkey CIMMYT/ICARDA International Winter Wheat Improvement Program (IWWIP) focuses on particular wheat areas in CWANA, mainly ME 7 and 9 and ME 10 and 12. In CWANA, winter and facultative wheats are produced mainly between 32^o to 42^0 N latitude. Annual precipitation is mostly below 400 mm, summers are hot and dry, and winters are often moderate. The most important wheat diseases are yellow rust, common bunt, leaf rust, tan spot, and dryland root rots. In contrast, winter wheat areas in CEE and Russia receive more than 500 mm of rain. Wheat areas are located between 42^o to 55^oN latitude and classified mostly under ME 11. The most important diseases are leaf rust, powdery mildew, fusarium head scab, *Septoria* spp., and barley yellow dwarf (BYD). Winters are often severe, and winterkill is frequently observed.

Based on climatic and geographic differences, adaptation requirements for wheats in this large area vary greatly. The adaptation of wheat cultivars developed by NARSs and the IWWIP for the mega-environments in CWANA and CEE is evaluated in yield trials targeted for the different MEs. The Winter Wheat East European Regional Yield Trial (WWEERYT) is targeted for the high rainfall areas in CEE. The irrigated areas in CWANA are addressed through the WWEERYT and the Elite Yield Trial for irrigated areas.

First and Second Winter Wheat East European Yield Trial (WWEERYT)

The WWEERYT consists of 60 elite cultivars plus four checks. The lines are submitted by 13 wheat programs in CEE, 4 programs in CWANA, 3 programs in the Great Plains of the US, and the IWWIP. The objective of this nursery is to evaluate elite germplasm from regional wheat programs across the region and to give NARSs access to these elite lines for use in their breeding programs or variety release. Co-operators are asked to sign a materials transfer agreement (MTA) before they receive the material.

In 98-99 and 99-00 the nursery was grown at 22 and 19 locations, respectively. Plot size at each location varied from 6 m^2 to 12 m^2 and the nursery has 3 replications. Plot size was large because several co-operators lack sowing equipment for smaller plots. The advantage of big plot size is that it increases the reliability of yield data. Table 1a and b lists entries whose yield was not different from the highest yielding entry either across all locations or across locations in CWANA or CEE. Yield is also given in % of the best of four local checks.

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[1] CIMMYT-Turkey;
[2] CIMMYT-Kazakstan;
[3] CIMMYT-Mexico

Only a few cultivars performed well in both regions. In the 1st WWEERYT, ERYT6221 from Mironovsk in Ukraine, derived from a mutation program, was equal or better than checks in 13 locations. The parents, TXGH2895 and Trakia, were lines from US, Texas, and Bulgaria. Agri//Bjy/Vee had the second highest mean yield across locations and was equal or better than the best of four checks at 10 locations. Yuna, a winter hardy facultative type from Krasnodar, Russia, also performed well in both regions. In the 2nd WWEERYT, five cultivars, one each from Bulgaria, Texas, and Romania and two from the IWWIP, performed well in both regions.

In the CEE region, the highest mean yield was obtained in the 1st WWEERYT by cultivars from programs located in CEE and TAM 200 from Texas A&M. Yields of cultivars developed by the IWWIP were different from those of the best entries, and equal or slightly lower than that of the local check. In the 2nd WWEERYT, cultivars from CEE, Texas, and the IWWIP had highest mean yields. The IWWIP lines are derived from selections made in Turkey.

Table 1a. Grain yield of highest yielding entries in 2nd WWEERYT (1999-2000) across 18 locations and across the 7 locations in CWANA and 11 locations in Eastern Europe.

			Total			East Europ. countries			CWANA countries			No. trials entry yield not sign. diff. from top yielder
Entry	Cultivar	Origin	Mean	Rnk	% LC	Mean	Rnk	% LC	Mean	Rnk	% LC	
40	Local Check		6049 *1	1	100	6425 *	1	100	5458 *	12	97	9
52	TODORA	BG	5962 *	2	99	6289 *	3	98	5448 *	14	97	11
56	SOM-5	TCI	5944 *	3	98	6090 *	8	95	5714 *	4	102	11
59	BOEMA	RO-FL	5942 *	4	98	6019 *	13	94	5821 *	3	104	11
64	TX96V2427	US-TX	5936 *	5	98	6087 *	9	95	5698 *	5	101	8
22	DOGU88//TX71 A374.4/TX71A 1039.V1/3/ F1502W9.1	TCI	5904 *	6	98	6126 *	6	95	5513 *	10	98	10
26	SHARK-1	MX-TCI	5867 *	8	97	5786	29	90	5995 *	1	107	8
25	KINACI97	MX-TCI	5843 *	10	97	5822	27	91	5876 *	2	105	7
5	MV MARTINA	HUN-MV	5650 *	19	93	6293 *	2	98	4640	52	83	8
2	SERI	MX	5288	43	87	5368	54	84	5162	25	92	0
1	BEZOSTAYA1	RUS	5023	59	83	5213	63	81	4725	49	84	2
	MEAN		5434			5706			5038			n=16 locations
	LSD		424			456			788			

Table 1b. Grain yield of highest yielding entries in 1st WWEERYT (1998-1999) across 18 locations and across the 7 locations in CWANA and 11 locations in Eastern Europe.

			Mean			Mean EEurope			Mean CWANA			No. trials entry yield not sign. diff. from top yielder
Entry	Cultivar	Origin	kg/ha		% LC	kg/ha	Rnk	% LC	kg/ha	Rnk	% LC	
52	ERYT26221	UKR-MI	6195 *	1	104	6067 *	1	108	6534 *	1	107	13
60	LOCAL CHECK 2		5941 *	2	100	5593 *	5	100	6072 *	9	100	5
9	AGRI/BJY//VEE	MX-TCI	5834 *	3	98	5435	17	97	6513 *	2	107	7
35	UKRAINKA	UKR-OD	5829 *	4	98	5701 *	2	102	5719	26	94	6
47	YUNA	RUS	5796 *	5	98	5589 *	6	100	5828	19	96	6
37	SELYANKA	UKR-OD	5700 *	7	96	5586 *	7	100	5569	38	92	4
26	BOKA	CZ	5692 *	8	96	5390	21	96	6103 *	7	100	4
23	MV MADRIGAL	HUN-MV	5661	9	95	5323	27	95	6184 *	5	102	4
4	KINACI97	MX-TCI	5621	14	95	5103	37	91	6284 *	3	103	5
27	SARKA	CZ	5511	24	93	5326	25	95	6132 *	6	101	5
63	TAM200	US-TX	5480	27	92	5612 *	3	100	4986	59	82	6
53	MNCH-24	MX	5219	44	88	4930	45	88	6221 *	4	102	5
2	SERI	MX-TCI	4536	61	76	4355	61	78	5145	55	85	0
1	BEZ	RUS	1818	64	83	4652	59	83	5456	45	90	2
	MEAN		5238			5067			5583			n=16 locations
	LSD		508			574			642			

*1 not significantly different from highest yielding entry using LSD 5%.

In both years three of the four highest yielding entries in CWANA originated from IWWIP. In general, IWWIP lines selected in either Turkey or Mexico perform well in CWANA (see results below). However, they often lack the winterhardiness required in CEE, since winters in Turkey and Mexico are much milder than in CEE. Furthermore, the IWWIP emphasizes winter x spring crosses. Cultivars derived from such crosses have sufficient cold tolerance for most areas in CWANA. An important factor that limits adaptation is the different disease spectra in CWANA and in CEE. Most IWWIP cultivars are resistant to yellow rust virulences prevailing in CWANA, whereas many lines from CEE and the Great Plains are susceptible. On the other hand, the widely adapted cultivars from CEE combine resistance/tolerance to powdery mildew, septoria, fusarium, and leaf rust, diseases of only local importance in the facultative and winter wheat areas of CWANA.

Though few lines perform well in both regions, in general there is a clear separation. TAM 200 and MV Martina had the second and third highest yield in 1st and 2nd WWEERYT, respectively, but were among the lowest yielding entries in CWANA. Similarly, Shark-1 and Kinaci 97 had the highest yield in CWANA, but only mediocre yields in CEE. This is not surprising, since yellow rust, the main disease in CWANA, is important only in Romania, whereas most lines selected in CWANA are susceptible to powder mildew, fusarium, leaf rust, and septoria, and less winter-hardy in the CEE region.

Fourth Elite Yield Trial for Irrigated Areas (EYT-IRR)

The Elite Yield Trial is grown in three replications and has 25 entries, including four long-term checks (Bezostaya, Kinaci, Katia, and Sultan) and one local check. Data from 23 sites in CWANA and from one site each in Morocco, Portugal, and Spain were available for analysis. Results for the checks and the highest yielding entries across eight locations in Central Asia-Caucasus, six locations in Iran, nine in Turkey, and five on the Anatolian Plateau are given in Table 2.

The highest yielding entries were Burbot-4, RPB868/CHRC//UT1567.121/3/ TJB368.251/ BUC, WXD880137A-9H-0YC-1YC-0YC-0YC-1YC-0YC, and Shark/F4105. Burbot derives from an F3 from Oregon and is relatively late maturing. It takes advantage of the full-irrigation regimes applied mostly on experiment stations. Both entries outyielded the best long-term checks by 2-14% and the local check by 5-20% in all regions. The highest yield advantage (14 and 11%) was obtained in trials

Table 2. Mean grain yield of highest yielding entries in 4th EYT irrigated and % of yield of best of 5 checks (BC%) across all 26 locations and across 8 locations in Central Asia/Caucasus, 6 locations in Iran, all 9 locations in Turkey, and 5 locations on the Anatolian Plateau.

		Grand mean 26 sites		C-Asia/Caucasus 8 sites		Iran 6 sites		Turkey 9 sites		Turkey-Anat. Plat. 5 sites	
Entry	Name	kg ha-1	% BC	kg ha-1	% BC	kg ha-1	% BC	kg ha-1	% BC	kg ha-1	% BC
1	BEZOSTAYA	3986	89	3417	80	4097	87	4836	90	5171	91
2	KINACI	4495	100	4288	100	4735	100	4849	90	5371	95
3	KATIA	4503	100	3752	88	4629	98	5373	100	5681	100
4	SULTAN	4365	97	4017	94	4480	95	5162	96	5493	97
5	LOCAL CHECK (LC)	4401	98	4048	94	4560	96	4840	90	5218	92
9	Shark/F4105	4922	109	4760	111	4806	102	5543	103	5751	101
14	BURBOT-4	4955	110	4870	114	4831	102	5588	104	5996	106
15	TAM200/KAUZ	4763	106	4759	111	4740	100	5213	97	5528	97
24	Shark/F4105	4735	105	4756	111	4074	86	5654	105	6018	106
25	TAM200/JI5418	4735	105	4248	99	4511	95	5583	104	5954	105
MEAN		4421				4454		4821		5472	
LSD5	336				708		564		896		

in CAC. In Turkey, the advantage over Kinaci 97 and Sultan 95, the latest variety releases for irrigated areas on the Central Plateau, is 6%. In Iran, the best check was outyielded by 2% and the local check by 5%.

This supports data from the WWEERYT that lines developed by the IWWIP are well adapted across large areas in CWANA. These lines combine yield potential with resistance to yellow rust and stable yields across the region. Kinaci 97 was released in Turkey, Afghanistan, and Uzbekistan.

At present only in Turkey and parts of Iran is supplementary irrigation a common procedure; in most other areas, full irrigation systems are applied. The latter favor late maturing cultivars. Due to the catastrophic droughts that have struck CWANA countries, growing public concern over water shortages, and increasingly intensive crop rotations, breeding early maturing cultivars adapted to supplementary irrigation regimes will become a high priority in most CWANA countries. Results from the EYT-IR suggest that lines adapted to supplementary irrigation systems are already available.

Progress in raising winter and facultative wheat yields

Bezostaya 1 was widely grown in CEE until 15 years ago and still is in several countries of CWANA. This was due particularly to its quality characteristics and grain plumpness. Bezostaya also has an excellent winter survival rate, as results of the Facultative and Winter Wheat Observation Nursery show. Distributed worldwide, this nursery includes elite wheat cultivars from Europe, North America, CWANA, and the IWWIP, but no entries that are cold tolerant in all environments. This is understandable, since the development, maintenance, and breakdown of frost tolerance are controlled by both genetic and environmental factors.

A large area is still sown to Bezostaya, perhaps partly due to its ability to cope with the wide range of stresses in cold environments; in contrast, other genotypes are more specifically adapted to cold stresses occurring in either humid or dry areas. This ability is of particular importance in areas where agronomic practices and seedbed preparation are poor, as is the case in large areas of WANA.

Data from the 1st and 2nd WWEERYT and the 3rd and 4th Elite Yield Trial for irrigated areas were used to estimate progress in increasing yields of new cultivars relative to Bezostaya. In total, data from 24 trials in CEE and 54 trials in CWANA during 98-99 and 99-00 were considered (Tables 3 and 4). The local check yielded below Bezostaya in 12 trials in CWANA and 1 trial in CEE. In none of the trials did Bezostaya have the highest yield. The highest yielding entry outyielded Bezostaya by at least 20% in 46 of 54 trials in CWANA and in 20 of 24 trials in CEE. In 26 trials in CWANA and 9 trials in CEE, the best check outyielded Bezostaya by more than 40%.

Table 3. Fifty-four trials in CWANA and 24 trials in CEE grouped on yield advantage (%) of Local Check and highest yielding entry compared to Bezostaya. Data from 1st and 2nd WWEERYT and 3rd and 4th Elite Yield Trial (irrigated), 1998-99 and 1999-00.

	Frequency of trials					
Yield range	Central / West Asia			Central Eastern Europe		
(% Bezostaya)	Local check	Best entry	Trial mean	Local check	Best entry	Trial mean
< 100 %	12	0	10	1	0	4
100 - 110 %	11	3	10	3	1	8
111 - 120 %	11	5	7	4	3	7
121 - 130 %	8	10	8	7	5	3
131 - 140 %	3	10	10	4	6	0
> 140 %	9	26	9	5	9	2
Total no. of trials	**54**	**54**	**54**	**24**	**24**	**24**

Progress is also obvious from the number of trials in which the mean yield of all entries is higher than the yield of Bezostaya (44 of 54 trials in CWANA and 20 of 24 trials in CEE). The average yield advantage of the highest yielding entry and the local check (using data from each location) was 46% and 27% in the 1st WWEERYT, 46% and 20% in the 2nd WWEERYT, 86% and 46% in the 3rd EYT, and 46% and 28% in the 4th EYT.

Similar data are found when the average yield across locations is used as basis (Table 4). Again, progress of the highest yielding cultivars over Bezostaya varies from 20% to 43% in CWANA and 23 to 30% in CEE. Using single-location and across-location data, it can be concluded that the yield of recently developed cultivars is at least 25% above that of Bezostaya.

Root Rot Screening

As noted above, the disease spectra are very dissimilar in CEE and CWANA, mainly due to different rainfall patterns. Among the major diseases in the dryland areas of the West Asia/ North Africa (WANA) region, root rots are also becoming increasingly important in areas with supplementary irrigation. In supplementary irrigation systems wheat is often not irrigated at the optimum time and can at times suffer from drought. Under such conditions, losses from dryland root rots in irrigated plots can be as high as 50%.

Disease occurrence and frequency vary regionally, depending on climatic conditions and agronomic practices. The most commonly reported root rot pathogens are *Cochliobolus sativus*, *Fusarium culmorum*, *Fusarium graminearum* (Group 1), *Fusarium avenaceum,* and *Rhizoctonia cerealis*. Root rots most often affect seedling stand, reduce yield, and lower grain quality. Typical symptoms include discoloration and necrosis or rotting of roots, subcrown internodes, crown, and/or the stem. Severe root rots cause symptoms such as stunting, late death tillers, and premature ripening; bleaching of spikes commonly known as “white heads” or “dead heads” may occur. Root rots can be caused by one or a combination of pathogens.

The use of resistant/tolerant cultivars is usually the most economic, sustainable, and environmentally sound control method. However, screening wheat for resistance to the root rot complex has been hindered by inadequate and inconsistent inoculation methods, and a lack of accurate and suitable disease evaluation techniques. Several studies were conducted in WANA to identify wheat germplasm resistant to this complex disease. In Turkey, however, very few studies have been conducted on root rots, and practically no screening of winter wheat germplasm.

Hence, a major effort to address root rots was undertaken in the IWWIP in the 1999-00 crop season. One thousand six hundred wheat genotypes, including most released cultivars and advanced lines, were artificially inoculated with the major root rot pathogens (*Cochliobolus sativus*, *Fusarium culmorum*, *Fusarium graminearum* (Group 1), and *Alternaria*). Root Rot Screening Nurseries were planted in Cumra Station, 40 km from Konya City, Turkey, where root rot is frequently observed. Each genotype was planted in two adjacent plots (2

Table 4. Mean yield and yield advantage (%) of best entry over Bezostaya across all locations of 1st and 2nd WWEERYT (18 trials) and 3rd and 4th EYT-irrigated.

	Central/West Asia			Central Eastern Europe		
	Yield (kg/ha)		Yield (%)	Yield (kg/ha)		Yield (%)
Nursery	Best entry	Bezostaya	Bezostaya	Best entry	Bezostaya	Bezostaya
1st WWEERYT (21 trials)	6534	5456	120	6067	4652	130
2nd WWEERYT (18 trials)	5995	4725	127	6425	5213	123
3rd EYT-irrigated (19 trials)	5145	3595	143			
4th EYT-irrigated (23 trials)	4955	3986	124			

rows, 2 m long). One plot was inoculated with a suspension of root rot spores, and the other plot (non inoculated) was the check. Root rot was evaluated from heading to maturity based on plant stand and white heads.

Results of these studies showed that 17 lines were tolerant in the most advanced International Nurseries (FAWWON, EYT, Winter Wheat Observation Nursery, irrigated and rainfed, and WWEERYT). Under rainfed conditions, lines selected from the 4th EYT-RF (FDL4/KAUZ and AGRI/NAC//KAUZ) and 3rd WON-SA (EBVD99-6 and CRR/TIA.2/FDL490) showed promise and are presently being evaluated for the second year to confirm their tolerance to root rot.

Among the 15 genotypes selected from yield trials were two widely grown cultivars, Gerek 79 and Gun 91. The reaction of these two cultivars has yet to be confirmed. The large areas sown to these cultivars (more than 1 million ha and 300,000 ha, respectively) indicate that their tolerance to root rots is partly responsible for their wide acceptance by farmers.

In total 225 genotypes (of the 1600 entries tested) were selected and will be tested in 2000-01 to confirm their reaction to root rot. Besides these entries, 1800 new genotypes will be tested for the first time for root rot reaction under artificial inoculation using similar techniques.

Nematode and Root Rot Surveys in Syria and Turkey

In the 1999-00 crop season, scientists from Turkey, CIMMYT, ICARDA, and France undertook a major survey of soil-borne diseases in the principal wheat-growing areas of Turkey and Syria. Its main objectives were to assess the importance and distribution of soil-borne diseases and identify the major causal agents. Fifty-three samples (soil and roots) were collected in total (23 in Syria and 30 in Turkey). In Turkey samples were collected at random every 50 km from Adana- Konya - Eskisehir-Ankara.

In Eskisehir (AARI) migratory nematodes (root lesion nematode, or RLN, *Pratylenchus* spp.), cysts (cereal cyst nematode CCN, *Heterodera* spp.), and samples of root rotting fungi (*Fusarium* spp. and *Bipolaris*) were extracted from soil/plant samples from Turkey. Preliminary results of these analyses showed that:

- 72% of root samples investigated had CCN cysts.
- 80% of soil samples contained one or both species of RLN.
- 60% of root extractions contained root rots (*Fusarium* spp. and/or *Bipolaris*).
- *Fusarium* spp. was isolated more frequently (57% of samples) and *Bipolaris* less so (17% of samples).
- At least two species of *Fusarium* were commonly isolated from roots (*F. graminearum* and *F. culmorum*).

These data confirm results of previous surveys: that root rots and nematodes are a widespread constraint for cereal production in Turkey. To address the root rot/nematode complex, a CIMMYT pathologist will be based in Turkey.

Farmer Participatory Variety Selection in South Asia

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The CIMMYT Wheat Program has been associated with the NARSs of South Asia for the last 35 years. Over this period, South Asian countries have identified and released many improved wheat varieties that have played an important role in increasing average grain yield and total production in the region. On average, South Asia maintained an annual production growth rate of 3.5% from 1985 to 1997 (Pingali, 1999). Despite these achievements, and due mainly to the high population growth rate (2.2% per year), by 2020 the region is expected to face a net trade deficit of 21 million tons of wheat grain, mostly in Pakistan, Bangladesh, and Nepal (Rosegrant et al., 1995; Table 1).

Average productivity in the more productive areas of South Asia (e.g., Punjab of Pakistan and India, Terai of Nepal, northern Bangladesh) has leveled off. Since the cultivated area in these countries increases by only 1% each year, the required jump in production will have to come from the less productive areas (e.g., eastern, far eastern, and central India, hills of Nepal, and northern and western Pakistan). In these marginal areas, the yield gap between experiment stations and farmers' fields is wider than in the more productive environments of the region. The most commonly grown varieties are old improved varieties such as Sonalika and HUW 234, as well as local, low-yielding, disease-susceptible varieties.

Table 1. Wheat production, consumption, and imports (in millions of tons).

	Production		Demand		Net trade	
Region / Country	**1990**	**2020**	**1990**	**2020**	**1990**	**2020**
World	530	841	532	841	-2	0
DC 304	409	242	287	62	122	
LDC	227	432	289	553	-62	-121
South Asia	66	127	69	148	-3	-21
Bangladesh	1	2	3	6	-2	-4
India	49	96	48	95	1	1
Pakistan	14	27	16	42	-2	-15
Other South Asia	1	1	2	3	-1	-2

Source: Rosegrant et al. (1995).

Besides the low adoption rate of improved varieties in these marginal areas, constraints such as poor seed production infrastructure and lack of appropriate technology transfer programs contribute to the wide yield gap. Another important factor is the lack of diversity in improved wheat varieties grown by farmers. This is very risky, since a single change in the virulence of a foliar pathogen could cause significant yield losses. Serious yield losses were reported in Pakistan (and other Asian countries) in the early 1990s, when the main variety grown at that time (Pak 81) was hit by a new race of yellow rust. Table 2 shows the total wheat area, average yield, production, and estimated area grown to a single variety in several countries during the 1999-2000 wheat season.

To help the NARSs of South Asia meet these challenges, for the past four years the CIMMYT Wheat Program has made special efforts to strengthen wheat research focused on the less productive areas of the region. Besides the ongoing exchange of germplasm and information, CIMMYT, through its South Asia regional wheat program, has

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Table 2. Wheat production statistics for South Asia, 1999-2000.

Country	Area (000 ha)	Yield (t/ha)	Production (000 t)	Area under one main variety (000 ha)
Bangladesh	700	2.4	1680	525 (=Kanchan, 75%)
India (Country)	27000	2.8	75640	4500 (=PBW 343, 16.7%)
India (North*)	5560	4.15	2309	4000 (=PBW 343, 71.9 %)
Myanmar	98	0.9	85	73 (=SKA, 75%)
Nepal	660	1.8	1188	200 (=NL 297, 30%)
Pakistan	9100	2.5	22500	6370 (=Inquilab 91, 70%)
South Asia	37558	2.7	101093	——————

* States of Punjab and Haryana only.

worked hand in hand with regional NARSs on farmer participatory variety selection (PVS) and farmer participatory plant breeding (PPB). Thanks to the active participation of resource-poor farmers, both approaches, especially PVS, have proved effective in promoting the adoption of new wheat varieties and of relevant site-specific resource conservation techniques (RCTs).

Farmer Participatory Approaches

Farmer participatory approaches for identifying or breeding improved crop cultivars can be categorized into participatory varietal selection and participatory plant breeding (Witcombe et al., 1996).

In PVS, farmers select finished or nearly finished products (released cultivars, varieties in advanced stages of testing, and advanced non-segregating lines) from plant breeding programs in their own fields. In contrast, in PPB farmers select genotypes from genetically variable, segregating materials. PPB may be used when PVS has failed, or when conventional plant breeding has not developed or identified a variety suitable for a specific, usually harsh, environment. The difference between PVS and PPB may at first seem negligible, but PPB requires more time and resources, while PVS identifies materials that the seed sector can supply more rapidly. Also, PVS and PPB have contrasting impacts on biodiversity (Witcombe and Joshi, 1995; Witcombe et al., 1996).

When scientists and farmers work together, they learn from each other and begin to understand the differences in their views and knowledge systems. By bridging this gap, they are able to develop solutions that respond to the perceived needs of farmers. Solutions oriented towards fulfilling these needs have greater potential for adoption and for achieving positive changes in farming systems.

Farmers' role in varietal selection

Farmers are usually involved only in the final stages of variety testing, generally after varieties have been identified for release. On-farm demonstrations and similar trials organized by extension services are managed with the full range of recommended external inputs, which can be atypical of the predominant management practices in the target region. Farmers have little or no input regarding the management of these trials or the varieties being tested. Farmers' evaluations of the tested genotypes are usually not sought, nor are their criteria applied, or if they are, they play little or no role in the decision-making process for varietal releases and recommendations (Farrington and Martin, 1988). However, possibilities for farmers' participation in selection are as diverse as the nature of selection itself, e.g., selection among single plants, progeny rows, experimental elite lines or varieties, selection on-station, or selection on their own farms (Weltzien et. al., 1998).

Farmer-Scientist Participatory Activities in South Asia

For the last three crop seasons, the CIMMYT-South Asia wheat regional program, in close partnership with NARSs and other stakeholders working in the region, has conducted PVS and PPB activities with the following objectives:

- To promote the adoption and dissemination of new varieties and site-specific resource conservation technologies

- To obtain farmers' assessments of new improved lines/varieties and specific traits
- To understand farmers' criteria in evaluating improved germplasm
- To obtain feedback from farmers for breeding purposes
- To demonstrate the value of combining improved varieties with resource conservation techniques

India

In the 1998-99 season, 40 farmers from two villages in the Varanasi area, State of Uttar Pradesh, were invited to participate in the assessment of improved wheat varieties/elite lines (including the old popular variety HUW 234). During this PVS exercise (jointly conducted with Banaras Hindu University staff), the improved variety HUW 468 was identified by farmers.

In the 1999-2000 season, PVS activities were again conducted in four farmers' fields in two villages (Karhat and Baouli). The farmer-preferred variety HUW 468 was compared with the old variety HUW 234 under conventional planting (broadcast seeding) using the normal planting date (mid November) and under zero tillage using a late planting date (late December/early January). Field days were organized to assess the preference of farmers for the introduced technologies.

Under conventional planting/normal seeding date, the variety HUW 468 yielded 15% more than HUW 234 (Figure 1) and maintained the same yield advantage when the two varieties were planted under zero tillage and late seeding date. Initially all farmers had serious reservations about zero tillage, but are now convinced of its advantages and willing to buy their own drills.

Excess moisture delays planting in the area, and in some years, no wheat is planted at all. By combining the improved variety HUW 468 with resource conservation technology, farmers in the rice-wheat areas of eastern Uttar Pradesh can plant their fields earlier, save on diesel, and increase their yields. A large scale effort with the participation of extensionists and NGOs working in the area is now underway to help disseminate these technologies.

PVS exercises during the 1999-2000 season in other villages in the area showed farmers' preference for newly released varieties such as HUW 510 and HUW 516. Farmers indicated tillering ability as HUW 516's most desirable trait. This information will help accelerate seed multiplication of the two varieties.

HUW 234 is highly susceptible to diseases such as helminthosporium leaf blotch and leaf rust. Thanks to PVS activities, this variety may be replaced soon, diversifying the spectrum of varieties grown in farmers' fields.

Nepal

PVS activities were conducted during 1999-2000 in two contrasting regions of Nepal: Bankatti Village, Rupandehi District in the Terai (lowlands), and Kotounge Village, Bahtapur District in Kathmandu Valley (mid-hills, 1000-1800 masl).

Bankatti Village, Rupandehi District, Bhairahawa (Terai). The number of improved varieties grown in farmers' fields is very high. The main varieties are NL 297, Bhrikuti, UP 2338, Rohini, BL 1473, Achyut, UP 262, BL 1022, and BL 1135. A PVS exercise was conducted to determine the criteria used by farmers in selecting wheat genotypes. Twenty farmers (men and women) were invited to participate and divided in two groups by gender. They were asked individually to list traits they would like in a wheat cultivar grown in their own farms, and to rank them.

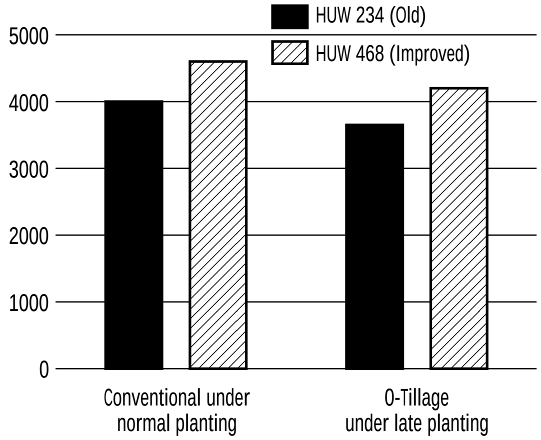

Figure 1. Grain yield (kg/ha) of old vs improved wheat varieties under conventional planting (Karhat Village) and zero tillage (Baouli Village) in Varanasi, State of Uttar Pradesh, India, 1999-2000.

Based on farmers' preferences, 12 wheat varieties with contrasting differences for the identified traits were planted in a replicated farmer-managed trial. At physiological maturity, farmers in both gender groups were asked to individually select wheat genotypes based on their preferred traits and to list the traits they preferred in the selected genotypes.

Women farmers gave priority to such traits as disease and insect pest resistance (Table 3), and then to chapati making quality and high grain yield. Male farmers' top priorities were late heat stress tolerance, large white grain, and shattering tolerance. Chapati making quality was a low priority for this group. The preferences of these two groups may indicate the need for developing varieties based on how they are used in the household. Women farmers are usually in charge of making bread and storing grain at home, while men farmers are more concerned with "filling the sacks."

Both gender groups ranked recently released BL 1473 at the top (Table 4) due to its early maturity, lodging tolerance, and bold, white grain. Based on these results, NARC will speed up seed multiplication of BL 1473. It will also take into account farmers' feedback in planning crosses and selecting populations in the breeding program.

Kotounge Village, Bahtapur District, Kathmandu Valley (mid-hills). During the 1999-2000 season, a PVS exercise was conducted in this village, located at approximately 1500 masl (mid-hills). The main wheat variety is the old, low yielding, and disease susceptible variety RR-21 (=Sonalika).

A set of 10 improved wheat lines and/or varieties was grown in a farmer-managed trial. A participatory field day was organized at physiological maturity to allow farmers to quantitatively assess the cultivars. Thirty farmers (men and women) ranked the wheat variety BL-1473 as the top performer in that set of genotypes. Farmers preferred the variety due to its early maturity, bold seed, good straw yield, high fertility, and lodging tolerance. BL-1473 yielded 30% more grain than RR-21.

Based on these results, about 1.2 t of foundation seed of BL-1473 were distributed to 60 farmers a few days before the 2000-2001 crop season began. We are optimistic that RR-21 will shortly be replaced by the new variety.

Results of a survey conducted a few days before the PVS exercise began showed that the ratio of new, improved vs old varieties (mainly disease susceptible RR-21) in the area was 10% to 90%. We are optimistic that this ratio will be reversed in 2001-02 and that the new variety will be adopted by farmers in the mid-hills, since 95% of seed dissemination occurs from farmer to farmer.

Pakistan

Lack of improved varieties, poor technology transfer, and a deficient seed multiplication system are mainly responsible for low wheat productivity in the northern hill region of Pakistan. Ten wheat varieties and elite lines developed by NARC's NWRP and the Turkey/CIMMYT/ICARDA Winter

Table 3. Ranking of farmer-preferred traits based on gender criteria, Bankatti Village, Rupandehi District (Terai), Nepal, 1999-2000.

Women:	Men:
• Disease resistance	• Late heat stress tolerance
• Pest resistance	• Large, white grains
• Good chapati-making	• Shattering tolerance
• High yield	• Disease resistance
• High tillering	• Lodging tolerance
• Medium height	• Early maturity
• White-bold seed	• High yield
• Lodging tolerance	• Medium height
• Large spikes	• Good chapati-making
• Shattering resistance	
• Short awns	

Table 4. Ranking of farmer-preferred varieties based on gender criteria, Bankatti Village, Rupandehi District, Nepal, 1999-2000.

Women:	Men:
• BL 1473	• BL 1473
• Nepal 297	• NL 731 and NL 297
• NL 731	• Bhrikuti
• BL 1724	• BL 1724 and BL 1692
• Bhrikuti	• NL 753

and Facultative Wheat Program were grown in 1999-2000 in 10 farmers' fields in northern Pakistan (1400-2800 masl).

At physiological maturity, 60 farmers quantitatively assessed a set of those cultivars in Sultanabad, Gilgit District. When asked to rank their preferred cultivars and list the reasons for selecting them, farmers consistently indicated three lines (in ranking order):

1. 951352 Zander (=1WWEERYT # 128)
   CIT88088T-0SE-6YC-0YC-2YC-0YC
2. 980815 8023.16.1.1/Kauz (=AYT # 9086)
   CMSW92WM00378S-0SE-0YC-2YE-0YC
3. 951273 VORONA/HD2402 (=EYT # 9818)
   SWM17702-0SE-13YC-0YC-2YC-0YC

The farmers' main reasons for choosing these lines were earliness, good straw, good head size, good lodging resistance, and bold white seed. The top three cultivars yielded 30-40% more than Suneen, the local variety (Table 5). Farmers like Suneen due to its straw yield, yet two farmer-preferred lines produced 5-6% more straw than Suneen.

The best varieties will be multiplied more extensively in 2000-01 to obtain enough seed to distribute to as many farmers as possible. Since most seed dissemination occurs from farmer to farmer, a large area should be sown to those varieties in 2-3 years.

Acknowledgments

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Table 5. Farmer-preferred wheat cultivars and their actual grain and straw yield, PVS Trial, Sultanabad Village, Northern Pakistan, 1999-2000.

Farmer-preferred cultivar (in ranking order)	Grain yield (kg/ha)	% of local cv	Straw yield (kg/ha)	% of local cv
951352 Zander	3808	140	5712	105
980815 8023.16.1.1/Kauz	3536	130	5768	106
951273 Vorona/HD 2402	3536	130	5440	100
Suneen (local cultivar)	2720	100	5440	100

Global Monitoring of Wheat Rusts, and Assessment of Genetic Diversity and Vulnerability of Popular Cultivars

R.P. Singh and J. Huerta-Espino

There are more than 40 diseases and insects that can cause economic losses to the wheat crop under various conditions. However, the greatest danger worldwide, in terms of severe crop losses, is the regional rust epidemics that can arise as a result of an attack by any of three airborne pathogens, i.e., *Puccinia graminis tritici*, *Puccinia triticina,* and *Puccinia striiformis*, that cause stem (black) rust, leaf (brown) rust, and stripe (yellow) rust diseases of wheat, respectively.

Why Monitor Rust Pathogens?

The most environmentally and farmer friendly strategy for reducing yield losses is the use of rust resistant cultivars. Resistances based on single, major, race-specific genes often become ineffective within five years of their deployment, producing "boom and bust" cycles in wheat production. The "bust" cycles (when rust resistance has been overcome) are caused either by pathogens mutating to acquire virulence, a virulent race migrating into a new region, or sexual and asexual recombination in the pathogen. Early detection of new virulences in pathogen populations makes it possible to replace susceptible cultivars with resistant cultivars in time to avoid large-scale epidemics.

Rust pathogens migrate from one region to another by wind movement. For example, virulence in *P. striiformis* for the *Yr9* gene evolved in East Africa and recently migrated to North Africa, West Asia, and South Asia all the way to Nepal (Figure 1). On the way, this *Yr9* race caused major epidemics in Ethiopia, Turkey, Iran, Afghanistan, and Pakistan. Concerted pathogen monitoring efforts, combined with knowledge of genetic resistance in cultivars and the governments' willingness to take prompt action, could have avoided or reduced the losses.

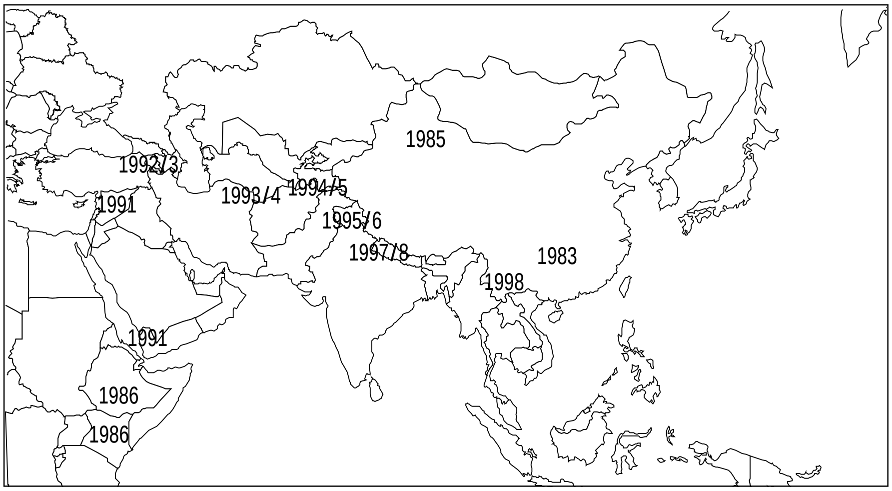

Figure 1. Movement of *Yr9* virulence.

Important cultivars whose resistance is based on a single race-specific gene, or combinations of a few of them, are currently grown over large areas in countries where yellow rust has caused major losses or posed serious threats in the past few years. Inquilab 91 (resistance based on *Yr27*) and PBW343 (resistance based on a *Yr3*/*Yr9* combination), the most important cultivars in northwestern Pakistan and India, respectively, are highly vulnerable. Virulences for *Yr27*, *Yr3*, and *Yr9*, and their combinations, are known to occur outside the region, *viz*. Mexico.

Inquilab 91 and PBW343 showed unacceptably low levels of adult plant resistance in Mexico when tested with a race virulent to the above genes. Similarly, a number of Kauz-derived varieties, e.g. Bakhtawar 94 (Pakistan), WH542 (India), Memof (Syria), Basribey 95 and Seyhan 95 (Turkey), and Atrak (Iran), were released following widespread epidemics in those countries on cultivars derived from Veery#5. The immunity of Kauz in these countries is due to the combination of *Yr9* and *Yr27*. Combined virulences for these two genes in the yellow rust population does not exist at present in the above countries; however, they are known to occur in Mexico. Slow rusting gene *Yr18*, also present in Kauz, does not by itself confer enough protection under high disease pressure (Ma and Singh, 1996[1]); hence Kauz shows unacceptable disease levels when tested in Mexico.

This type of information on the genetic basis of resistance would be extremely useful for a country preparing for a potential epidemic and trying to diversify the crop by promoting genetically diverse cultivars.

CIMMYT's External Program and Management Review panel in 1997 made a strong recommendation to the Wheat Program to reinitiate monitoring of changes in virulence of the rust pathogens. This could have avoided the large-scale epidemic of yellow rust that occurred recently. This recommendation was later endorsed by the Technical Advisory Committee of the CGIAR.

Breeding for rust resistance at CIMMYT, which began in the late 1960s and early 1970s, has moved a long way away from the use of major, race-specific genes and currently focuses on combinations of minor, slow rusting genes that impart durability of resistance. However, all cultivars currently grown in developing countries are not likely to possess such resistance. Until a majority of cultivars carry durable resistance, as is the case for stem rust, monitoring the rust pathogens and simultaneously evaluating the type of resistance in the main cultivars are considered essential for avoiding losses. Leaf and yellow rusts, of high to moderate importance in all wheat growing regions, will be the focal diseases. Stem rust is currently considered important in Africa and parts of the Southern Cone of South America.

In the 1980s CIMMYT established collaborative arrangements with the Cereal Rust Laboratory, St. Paul, Minnesota, and IPO, Wageningen, the Netherlands, where samples of rusts for virulence analysis could be sent from anywhere in the world. However, such arrangements have no longer been possible following the retirement of key scientists in the above labs. After some discussion, the decision was made at CIMMYT to promote the establishment of Regional Monitoring Nurseries.

Epidemiological Regions for Monitoring Nurseries

In developing countries wheat is grown in six epidemiological regions that are not necessarily fully isolated (Table 1). Though rusts can cross boundaries between these regions, this may take more time than moving within a given region, where movement is less restricted. Eastern and Southern Africa may well be separate regions; however, due to the recent introduction of yellow rust into South Africa and to increased human migration between the two regions, the African NARSs have decided to grow a common monitoring nursery.

Table 1. The six regions participating in the monitoring of rust pathogens.

Region	Rusts
Indian Subcontinent	Leaf rust, yellow rust
China	Leaf rust, yellow rust
West Asia and North Africa[1]	Leaf rust, yellow rust
Eastern and Southern Africa	Stem rust, leaf rust, yellow rust
Central Asia	Yellow rust, leaf rust
Southern Cone of South America	Leaf rust, yellow rust

[1] In collaboration with ICARDA.

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[1] Ma, H., and R.P. Singh. 1996. Contribution of adult plant resistance gene *Yr18* in protecting wheat from yellow rust. Plant Dis 80:66-69.

Monitoring nurseries

The nurseries have a group of common entries: near-isogenic lines for the named *Lr* and *Yr* genes, a group of cultivars carrying known gene combinations, and a group of cultivars/lines of international significance (Table 2). Seeds of these lines were shipped to CIMMYT's outreach programs or designated NARSs for increase during the 1999 and 1999-2000 crop seasons. A set of important cultivars grown in each of the regions forms the supplementary regional set. Regional nurseries are being grown (beginning in the 2000-2001 crop season) at carefully selected key sites in each region and a few selected hotspots outside the region. This will enable us to put regional information into a global context.

Data collection and analysis

Each entry will be evaluated for disease severity and reaction by the NARS at each site where disease occurs. Otherwise, the lack of disease will be recorded. Rust samples will be collected for pathogenicity (virulence/avirulence) analysis and shall be sent to a designated laboratory in regions where such facilities exist (Table 3). In regions where there are such facilities in some countries but not in others, we are trying to negotiate agreements whereby countries that have facilities will provide support to those that do not. Whether we will succeed remains to be seen. Quarantine regulations are the greatest barrier to moving diseased samples between countries. Leaf and stem rust samples of high importance could be analyzed at the Cereal Disease Laboratory in St. Paul, Minnesota, by J. Kolmer.

Race-specific genes present in regional cultivars will be postulated and the level of minor genes-based slow rusting resistance assessed, where possible. This work will be done in Mexico by CIMMYT and by C. Wellings at the University of Sydney.

Information on virulence in pathogen populations, race-specific resistance genes, and the presence of slow rusting resistance in the cultivars will be utilized to determine the probable genetic vulnerability and risk of continuing to cultivate specific cultivars in particular regions. This information will be shared on a regular basis with NARS scientists and decision makers in each country.

Table 2. Structure of rust monitoring nurseries.

Type of entry	Number
Near-isogenic lines for *Lr* genes	39
Durum wheats	5
Cultivars with known combinations of *Lr* genes	13
Cultivars with slow rusting resistance to LR and YR	12
Highly susceptible cultivar Morocco	1
Near-isogenic lines for *Yr* genes	15
Important cultivars grown in the region	20 to 40 entries
Single gene lines for *Sr* genes (only in Africa)	about 40 entries

Table 3. Regional scientists and laboratories collaborating in race identification.

Region	Regional Rust Laboratory	Pathogen
Indian Subcontinent	S.K. Nayar, DWR Regional Station, Flowerdale, Shimla, India	Leaf rust, Yellow rust
China	W.Q. Chen, Institute of Plant Protection, CAAS, Beijing, China	Leaf rust, Yellow rust
West Asia and North Africa	M. Torabi, SPII, Karaj, Iran	Yellow rust
Eastern and Southern Africa	C. le Roux, SGI, Bethlehem RSA	Stem rust, Leaf rust, Yellow rust
Central Asia	?	
Southern Cone of South America	A. Barcellos, Embrapa Trigo, Passo Fundo, Brazil	Leaf rust, Stem rust
	S. German, INIA, Colonia, Uruguay	Leaf rust

Marker-Assisted Selection for BYDV Resistance in Wheat

M. Henry, M. van Ginkel, and M. Khairallah

Barley yellow dwarf (BYD) is the most important viral disease of cereals. It has a worldwide distribution and infects a wide range of gramineae, including the major cereal crops. The disease is caused by five insect-transmitted luteoviruses, collectively known as barley yellow dwarf virus. The serotypes are PAV, MAV, RPV, RMV, and SGV (Waterhouse et al., 1988). PAV is the most severe and most common serotype, followed in occurrence by MAV and RPV.

Control of the disease can be partially achieved through the application of insecticides, cultural practices (such as changes in sowing date, alternate cropping, and removal of virus reservoirs), and the use of germplasm with tolerance or resistance to the virus or its vectors. In the sense of Cooper and Jones (1983), tolerant lines present attenuated symptoms and lower yield losses even though they multiply the virus. In resistant lines, virus multiplication and spread are inhibited or reduced, which may or may not attenuate symptoms. Tolerance to BYD in bread wheat has been reviewed by Burnett et al. (1995). Though not present in bread wheat, true resistance has been identified in several wheat relatives, such as *Thinopyrum intermedium.* Banks et al. (1995) successfully transferred this alien-derived resistance to bread wheat and produced a series of translocated lines (so-called TC lines) using tissue culture.

Previous observations showed that lines in the TC14 group had the most potential for wheat breeding because they showed low virus concentrations after infection with BYDV–PAV, –MAV, or –RPV (Henry, 1997) and carried the smallest translocation (Hohmann et al., 1996). However, though resistant, these lines were poorly adapted to the Mexican environment and sensitive to the infection; they would thus exhibit severe symptoms in the field when infected (Henry, 1997). In light of these findings and to achieve better BYDV control, our strategy has been to combine the alien-derived resistance with tolerance in good agronomic backgrounds.

Resistance induced by the *Th. intermedium* translocation was found to be associated with a reduction in virus titers of BYDV-PAV under field and greenhouse conditions and a lower infection rate when artificially inoculated with BYDV-PAV or MAV in the field (Ayala et al., 2001). A reduction in virus titers was also observed with BYDV-MAV and RPV under greenhouse conditions (Henry, unpublished data).

At CIMMYT, screening for BYD has been based mainly on observation of symptoms after natural or artificial inoculation and has focused on identifying tolerance to the disease. Screening for resistance is laborious, involving artificial inoculation in the field or greenhouse and measuring virus titers by ELISA (enzyme-linked immunosorbent assay); to combine resistance with tolerance, lines are screened for low symptoms under infection. To complicate matter even more, expression of tolerance and resistance is strongly influenced by environmental conditions.

To overcome some of the constraints of testing for BYD tolerance and resistance, a search for molecular markers for these traits was undertaken. An SSR (simple sequence repeat) marker, *gwm37,* identified by Ayala et al. (2001), shows polymorphism between resistant TC14 lines and bread wheat. It is a diagnostic co-dominant marker that differentiates individuals possessing the *Th. intermedium* introgression (Ti) in homozygocity or heterozygocity from those not carrying it. Tolerance proved to be controlled by several QTLs with small effects, for which no diagnostic markers could be identified (Ayala et al., unpublished data). In this paper, we report the use of *gwm37* in a marker-assisted selection strategy to incorporate *Th. intermedium*-derived resistance into high yielding bread wheats. The strategy involved selecting tolerant progeny for BYD resistance as a way of overcoming some of the limitations of the resistant but sensitive TC14 parents.

Materials and Methods

Selection strategies

Resistant lines TC14/2*Spear and TC14/2*Hartog (CSIRO 289B, 289X), kindly provided by Philip Banks, CSIRO, Australia, were crossed to about 50 advanced CIMMYT wheats representing materials adapted to irrigated, high rainfall, and/or drought environments. The materials were shuttled between a coastal irrigated site, Cd. Obregon in northwestern Mexico, and a high rainfall location near Toluca, in the central highlands of Mexico. Diseases prevalent in the two sites are different, and include leaf, stripe, and stem rusts, *Septoria tritici*, fusarium head blight, and a complex of soil-borne diseases. The best F2 plants within a cross were harvested in bulk. Selection criteria included good agronomic type, durable disease resistance, synchronous tillering, desired spike type and size, good fertility, appropriate height and maturity, as well as well-filled grains. Within the F3 and F5 plots, the best plants were selected, harvested, threshed in bulk, and visually checked for grain characteristics.

In the F4 and F6 generations, individual plants or lines were grown in Toluca under high natural disease pressure. They also underwent selection with artificial BYDV-PAV (Mexican isolate) inoculation in El Batán, also in the central Mexican highlands. Outstanding plants were visually selected at heading based on reduced or no BYD symptoms. The presence of the introgression (resistance allele) was then assessed using the SSR molecular marker *gwm37*. Resistant plants or lines were confirmed by measuring virus titers using ELISA.

BYDV testing

BYDV testing was carried out during the summer cycle at CIMMYT, El Batán, Mexico, in June 1999 and 2000. Seedlings were inoculated at the 3-leaf stage (Zadoks'13, Zadoks et al., 1974). The F4s were space planted in a 4 x 5 m plot with double rows, while the F6s were sown in paired 1-meter double plots, one being infected and the other kept free of aphids through regular insecticide application.

ELISA (enzyme-linked immunosorbent assay)

Double antibody sandwich ELISA (DAS ELISA) was used as described by Ayala et al. (2001). Optical density (OD) was measured at 405 hm using a MR 700 Microplate reader (Dynatech Laboratories). A plant was considered infected when the OD was higher than twice the OD of the non-infected control. ELISA values were classified as follows: Low: OD<0.25, Moderate: 0.25<OD<0.4, High: OD>0.4. In testing the F4s, the average OD value obtained for the resistant TC14/2*Spear was 0.131±0.098.

Determining the presence of the translocation

The presence of the translocation was assessed using the SSR marker as described in Ayala et al. (2001). Plants or lines were classified as homozygous resistant (TiTi), susceptible (titi) or heterozygous (Titi).

Results and Discussion

Four of the sixteen populations advanced to F4 were discarded after field evaluation in Toluca because of their high sensitivity to yellow rust. In El Batán, from the 12 remaining populations, 479 plants were selected based on their good appearance after BYDV inoculation. This group included plants not presenting any BYD-like symptoms and appeared to have escaped infection. As reported previously, this characteristic is also associated with *Th. intermedium* resistance (Ayala et al., 2001; Henry and Segura, 1999).

The range of OD values obtained in the selected lines with low symptoms levels was high (0.079-1.158), indicating that some plants were good hosts for the virus without presenting severe symptoms and thus could be qualified as tolerant.

PCR analysis was completed on 403 of the 479 plants selected. Of those, 34.5% were homozygous for the translocation (TiTi), 17.4% heterozygous (Titi) and 48.1% did not carry the fragment at all (titi).

A high proportion of the non-infected lines were either homozygous or heterozygous for the *Th. intermedium* fragment confirming the effect of the translocation on the incidence of infection (Table 1). Though the virus titers were distributed in three classes (low, medium or high), there was a tendency for the homozygous lines (TiTi) to have low or medium ODs, while the lines without the translocation (titi) had virus titers in the medium or higher classes.

Lines with reduced symptoms, low virus titers, or no infection, and shown to be homozygous for the translocation were selected and advanced to the F5. In total 156 lines were selected and tested for good agronomic characteristics in Obregon. Fifty-eight lines were advanced to the F6. In the F6, 10 were finally selected as having BYDV resistance (homozygous for the translocation, low virus titers) and some level of tolerance. Their resistance/ tolerance will be re-evaluated for an additional season.

In Toluca, selection among F4 populations was based on good agronomic characteristics, resistance to stripe rust, and some level of BYDV tolerance. One hundred and ninety-six plants were selected from the 12 crosses mentioned above. The distribution of selected plants in the three genotypic groups was different from the one obtained in El Batán. There was a higher proportion of heterozygous individuals in Toluca (41.8%) than in El Batán (14.8%), and a lower proportion of individuals not carrying the translocation in Toluca (9.7%) than in El Batán (40.5%). This indicates that during initial selection for BYD tolerance, a high proportion of plants not carrying the translocation were chosen, possibly because the translocation is not associated with tolerance.

A total of 177 plants (missing data, TiTi, and Titi) selected in Toluca were advanced to the F5. Forty lines were tested as F6s and nine were finally selected as carrying both resistance and tolerance to BYDV.

The data suggest that selection based on the presence of the translocation as detected with the molecular marker *gwm37* can be used in early generations, thus avoiding the need for special field screening. This should be followed by one or two cycles of testing under BYDV infection and estimation of virus titers to make sure resistance is still expressed. Final evaluation of true resistance as expressed in reduced virus titers can also be done in the greenhouse. However, to combine resistance and tolerance, screening under BYD pressure is recommended at least every other cycle. In addition, because our task at CIMMYT is to provide germplasm adapted to different

Table 1. Distribution of selected F4 individuals among genotypic groups (based on *gwm37*) and classes of virus titers under BYDV pressure in El Batán.

	Percentage of individuals			
Virus titer	Homozygous (TiTi)	Heterozygous (Titi)	No translocation (titi)	Missing data
Not infected	28.8	8.6	2.6	4.0
Low	41.7	37.1	27.3	37.3
Medium	21.6	42.9	40.2	37.3
High	7.9	11.4	29.9	21.3

Table 2. Distribution of selected F4 individuals in three genotypic groups (based on *gwm37*) under selection with (El Batán) or without BYDV pressure (Toluca).

	Percentage of individuals	
Genotypic groups	El Batán	Toluca
Homozygous resistant (TiTi)	29.0	17.3
Heterozygous (Titi)	14.8	41.8
Homozygous susceptible (titi)	40.5	9.7
Missing data	15.7	31.1

environments with strong disease pressure, in particular rusts, it is important to alternate screening under BYD pressure with other diseases, such as leaf and stem rusts (Cd. Obregon) and yellow rust (Toluca).

We have obtained a set of 19 lines (Table 3) combining BYDV resistance and (apparently) a certain level of tolerance. Tolerance to BYD in wheat is polygenic in nature, based on the action of minor genes. It is more important to have uniform infection when selecting for minor gene resistance than for major gene resistance (Qualset, 1984). In crosses with *Th. intermedium*-derived material, escape from infection is more common than in susceptible wheat, resulting in non-uniform infection. A sensitive plant might be rated as tolerant if it did not get infected. To minimize the error due to the escape mechanism and because BYD expression is strongly associated with the environment, it is important to confirm the tolerance identified in this work through another cycle of testing.

The molecular marker *gwm37* has proven to be a reliable tool for incorporating BYDV resistance, accelerating the process, and reducing the need for continuous testing under BYDV infection. This marker has been used successfully in selecting other populations, such as backcrosses with tolerant BYD germplasm.

Table 3. List of F6 lines carrying both resistance and tolerance to BYDV.

Pedigree	Selection history
TC14/2*HTG//HUITES	CMSS97M00087S-030M-020Y-10BYB-010Y
TC14/2*HTG//HUITES	CMSS97M00087S-030M-020Y-11M-010Y
TC14/2*HTG//HUITES	CMSS97M00087S-030M-020Y-13BYB-010Y
TC14/2*HTG//HUITES	CMSS97M00087S-030M-020Y-17M-010Y
TC14/2*HTG//HUITES	CMSS97M00087S-030M-020Y-3BYB-010Y
TC14/2*HTG//HUITES	CMSS97M00087S-030M-020Y-5BYB-010Y
TC14/2*HTG//HUITES	CMSS97M00115S-030M-020Y-22BYB-010Y
TC14/2*HTG//TRAP#1/BOW	CMSS97M00095S-030M-020Y-12M-010Y
TC14/2*HTG/3/VEE/PJN//2*TUI	CMSS97M00089S-030M-020Y-10M-010Y
TC14/2*HTG/3/VEE/PJN//2*TUI	CMSS97M00089S-030M-020Y-1BYB-010Y
TC14/2*HTG/3/VEE/PJN//2*TUI	CMSS97M00089S-030M-020Y-5BYB-010Y
TC14/2*SPEAR//HUITES	CMSS97M00115S-030M-020Y-16BYB-010Y
TC14/2*SPEAR//MILAN	CMSS97M00168S-030M-020Y-12M-010Y
TC14/2*SPEAR//MILAN	CMSS97M00168S-030M-020Y-16M-010Y
TC14/2*SPEAR//MILAN	CMSS97M00168S-030M-020Y-1BYB-010Y
TC14/2*SPEAR//MILAN	CMSS97M00168S-030M-020Y-3BYB-010Y
TC14/2*SPEAR/3/BOW/URES//KEA	CMSS97M00151S-030M-020Y-10M-010Y
TC14/2*SPEAR/3/BOW/URES//KEA	CMSS97M00151S-030M-020Y-14M-010Y
TC14/2*SPEAR/3/BOW/URES//KEA	CMSS97M00151S-030M-020Y-1M-010Y

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Durable Resistance to Yellow (Stripe) Rust in Wheat

R.P. Singh, S. Rajaram, J. Huerta-Espino, and M. William

Yellow (or stripe) rust, caused by *Puccinia striiformis tritici*, is an important disease of wheat in most cool wheat-producing regions. Using resistant cultivars is the best disease control strategy, since it comes at no extra cost to the farmer and is environmentally safe. Historically, race-specific major genes have been used to breed rust resistant wheat cultivars. At present 30 resistance genes have been catalogued (McIntosh et al., 1998). Most are race-specific in nature, and virulence for several of them has been identified somewhere in the world. One of the main objectives of CIMMYT's wheat improvement program is to generate genetically diverse germplasm that has high yield potential, wide adaptation, and durable resistance to important diseases such as the rusts.

Durable resistance as defined by Johnson (1978) is one that has remained effective in a cultivar during its widespread cultivation for a long sequence of generations or period of time in an environment favorable to a disease or pest. Johnson (1978; 1988) described the presence of durable resistance in some European wheat cultivars and indicated that such resistance is quantitative in nature. The moderate level of adult plant resistance of CIMMYT-derived North American cultivar 'Anza' and good level of resistance in Mexican cultivar 'Pavon 76' have shown durability (Rajaram et al., 1988). During the early 1990s research was initiated to identify CIMMYT wheats that may carry durable resistance, understand the genetic basis of such resistance, and develop selection strategies to breed such resistance in newer CIMMYT wheats. Key knowledge developed during the last decade of research is summarized here.

Yr18 and other minor genes for durable resistance to stripe rust

Independent results obtained by Singh (1992) and McIntosh (1992) indicated that the moderate level of durable adult plant resistance in Anza and winter wheats such as Bezostaja is controlled in part by the *Yr18* gene. Gene *Yr18* is completely linked with gene *Lr34*, known to confer durable leaf rust resistance. The level of resistance it confers is usually not adequate when present alone. However, combinations of *Yr18* and 2-4 additional slow rusting genes result in adequate resistance levels in most environments (Singh and Rajaram, 1994). Results of genetic analyses indicate that the level of resistance increases with the increase in the number of these genes that individually have minor to intermediate but additive effects. Cultivars carrying such *Yr18* complexes are listed in Table 1.

Genes *Lr34* and *Yr18* occur frequently in germplasm developed at CIMMYT and in various other countries. Using Jupateco 73 near-isogenic

Table 1. Seedling susceptible bread wheats that carry good adult plant resistance to stripe rust in field trials in Mexico and other countries.

Genotype(s)	Usual yellow rust response[1]	Additive for genes[2] resistance
Jupateco 73S (check)	100 MS	Moderately susceptible
Jupateco 73R	50 M	*Yr18*
Parula, Cook, Trap	15 M	*Yr18* + 2 genes
Tonichi 81, Sonoita 81, Yaco	10 M	*Yr18* + 2 or 3 genes
Chapio, Tukuru, Kukuna, Vivitsi	1 M	*Yr18* + 3 or 4 genes
Amadina	30 M	3 genes
Pavon 76, Attila	20 M	3 genes

[1] The yellow rust response data from Mexico have two components: % severity based on the modified Cobb scale (Peterson et al., 1948) and reaction based on Roelfs et al. (1992). The reactions are M = moderately resistant to moderately susceptible, sporulating stripes with necrosis and chlorosis; and S = sporulating stripes without chlorosis or necrosis.

[2] Minimum number estimated from genetic analysis.

reselections, studies at CIMMYT have shown that gene *Yr18* increases latent period and decreases infection frequency and length of infection lesions (stripes) in greenhouse experiments inoculated with yellow rust (Table 2). This indicates that components of slow rusting associated with *Yr18* are under pleiotropic genetic control. Diversity for minor genes is quite high; almost all of the more than 300 released cultivars studied by us have shown the presence of small to moderate and, occasionally, high levels of adult plant resistance.

Intercrosses among wheats listed in Table 1 have shown that although *Yr18* is a frequently occurring resistance gene, at least 10 to 12 additional slow rusting genes that have minor to intermediate effects are present in the wheat lines studied. Transgressive segregation leading to resistance levels superior to those of the parents was common in all intercrosses of the resistant parents. Cultivars such as Pavon 76 and Attila do not carry *Lr34* but possess other minor genes that confer adult plant resistance.

Because it can develop systemically, stripe rust is different from the other two rusts, where every new pustule develops from a new infection. The epidemiology of stripe rust is also different from that of the other two rusts. Johnson (1988) presented examples of adult plant resistance genes that are race-specific in nature. It is difficult to distinguish such resistance from the resistance conferred by genes of race-nonspecific nature, based on the adult plant infection type. Low disease severity to stripe rust is most often associated with at least some reduction in infection type. However, we have observed that in the case of potentially durable slow rusting resistance, the first uredinia to appear are moderately susceptible to susceptible. Subsequent growth of fungal mycelium causes some chlorosis and necrosis; therefore, the final infection type is usually rated as moderately resistant-moderately susceptible. Durability of such resistance can be expected if the cultivar's low disease severity is due to the additive interaction of several (4 to 5) partially effective genes.

Table 2. Comparison of three components of slow rusting resistance to stripe rust in seedling and flag leaves of near-isogenic *Yr18* Jupateco 73 reselections tested at 15 ^{0}C.

Genotype	Latent period (days)	Infection frequency (stripes / cm^2)	Length of stripes (mm)
Jupateco +*Yr18*	20.1	0.7	12.5
Jupateco -*Yr18*	15.9	7.1	47.7

Genetic linkage/pleiotropism of resistance genes

Genetic linkage between slow rusting genes *Lr34* and *Yr18* was mentioned above. Our recent results show that durable stem rust resistance gene *Sr2* is closely linked to minor gene *Yr30* conferring yellow rust resistance (Singh et al., 2000b). Quantitative trait locus (QTL) analysis of slow rusting resistance to leaf and yellow rusts in two recombinant inbred populations at CIMMYT has shown that several QTLs conferred resistance to both these rusts (Table 3). As shown in Table 3, disease-specific QTLs were also present for both leaf and yellow rusts, indicating that close genetic linkage or pleiotropism is not a rule. Slow rusting leaf rust resistance gene *Lr46* was linked to a gene for slow rusting yellow rust resistance, recently designated by us as *Yr29*. Functional aspects of slow rusting genes will be better understood once the genes are cloned. Because the same, or closely linked, minor, slow

Table 3. QTLs for slow rusting, additive genes involved in resistance to leaf and yellow rusts of wheat mapped by evaluating RILs from crosses of susceptible wheat 'Avocet S' and resistant 'Pavon 76' and 'Parula' for three years at field sites in Mexico.

			Disease severity reduction (%)		
Cultivar	Location	Marker	Leaf rust	Yellow rust	Named genes
Pavon 76	1BL	Wms259	35	27	*Lr46*, *Yr29*
	4B	Wms495	18	15	
	6A	Wms356	14	18	
	6B	PaggMcaa	-	18	
	3BS	PacgMcgt	-	11	*Yr30*, *Sr2*
Parula	7DS	*Ltn*[1]	56	46	*Lr34*, *Yr18*
	7B or 7D	Pcr156	29	-	
	1BL	Wms259	15	16	*Lr46*, *Yr29*
	Unknown	PaagMcta	22	14	
	3BS	Glk2	-	12	*Yr30*, *Sr2*

[1] Leaf tip necrosis, a morphological marker linked to gene *Lr34*.

rusting genes confer resistance to more than one rust disease, generating multiple rust resistance germplasm should be simpler than is usually thought.

Selecting for resistance based on additive minor genes

It is often believed that selecting for resistance based on additive interactions of minor genes is difficult. However, at CIMMYT the following steps aimed at enhancing the accumulation of such genes are being taken:

- Selecting parents that lack effective major genes and have moderate to good levels of slow rusting resistance to local rust pathotypes. Such parents are easily identified by testing them at the seedling stage in the greenhouse and as adult plants in the field using the same pathotype. Parents of interest should show susceptibility as seedlings and slow rusting as adult plants in the field. Known cultivars with durable resistance are also included.
- Maintaining genetic diversity. Based on available information, parents having different sets of additive genes are used in crossing. If such information is not available, parents of diverse origins or diverse pedigrees are selected for crosses.
- Establishing high disease pressure in the breeding nursery with chosen rust pathotypes. Spreader rows are planted at optimum distance and artificially inoculated to ensure homogeneous disease spread of desired rust pathotypes in breeding plots. Susceptible and slow rusting checks are included to assess disease pressure.
- Selecting plants with low to moderate terminal disease severity in F_2 and F_3, and from F_4 onwards selection of plants or lines with low terminal severity. Because adequate resistance levels require the presence of 3 to 5 additive genes, the level of homozygosity from the F_4 generation onwards is usually sufficient to identify plants or lines that combine adequate resistance with good agronomic features. Moreover, selecting plants with low terminal disease severity under high disease pressure means that more additive genes may be present in those plants.
- Maintaining leaf tip necrosis or mild pseudo-black chaff phenotypes. Because leaf tip necrosis is linked with durable resistance genes *Lr34* and *Yr18*, and pseudo black chaff is linked with *Sr2*, these traits are useful morphological markers.
- Conducting multilocational testing. As discussed earlier, multilocational testing of useful advanced lines can indicate the effectiveness and stability of resistance across environments. Based on the results, new lines are identified for future crossing.
- Genetically analyzing selected lines to confirm the presence of resistance based on additive genes.

Following the methodology described above, we have successfully combined high levels of resistance (comparable to near-immunity) to leaf and yellow rusts with high grain yield potential in wheat lines such as Chapio, Tukuru, Kukuna, and Vivitsi (Table 1) (Singh et al., 2000a). Genetic analysis of such resistance has shown that at least 4 or 5 minor, additive genes confer resistance to both leaf and yellow rusts. These wheat lines can be released directly for cultivation or can be used in future breeding programs.

A Challenge for the Next Decade

The challenge in the next decade will be to release several durably resistant cultivars and convince farmers to adopt them. The level of adult plant resistance in these cultivars must be adequate to meet the stringent requirements for release set in each country and to ensure that losses will be negligible even under high disease pressure. One approach currently taken by us is to incorporate durable resistance through limited backcrossing in important currently grown cultivars. A few exemplary cultivars are Inquilab 92 in Pakistan and PBW343 in India. Because these cultivars are moderately susceptible in Mexico, durable resistance genes can be incorporated. We hope that the derived lines will be similar to the original cultivar for most agronomic features but possess durable rust resistance and higher yield potential. Results of similar efforts using an Attila line released in Ethiopia indicate that it is possible to simultaneously improve resistance and yield potential. Durably resistant derivatives should have better acceptance by farmers.

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Applying Physiological Strategies to Wheat Breeding

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Physiological Basis of Improved Yield and Biomass Associated with the *Lr19* Translocation from *Agropyron elongatum*

Although wheat yields have continued to improve over the last 30 years (Calderini et al., 1999), the physiological and genetic bases for this improvement are only partially understood (Reynolds et al., 1999). Nonetheless, yield increases in several backgrounds have been shown to be associated with introgression of a chromosome segment containing *Lr19*, namely Agropyron 7DL.7Ag (Rajaram, Singh, and Montoya, unpublished data). The introgression of *Lr19* has also been reported to be associated with increased biomass (Singh et al., 1998).

As yield improvements due to increased partitioning of biomass to grain yield reaches its theoretical limit (Austin et al., 1980), breeding for larger total biomass becomes increasingly necessary if further genetic gains in yield potential are to be realized. Higher biomass may be achieved by: 1) increased interception of radiation by the crop; 2) greater intrinsic radiation use efficiency (RUE) throughout the crop cycle, and 3) improved source-sink balance permitting higher sink demand and, therefore, higher RUE during grainfilling. Increased light interception could be achieved via early ground cover or improved "stay-green" at the end of the cycle. Improved RUE may be achieved, for example, by decreasing photorespiration or photoinhibtion (Loomis and Amthor, 1999), or through improved canopy photosynthesis related to factors such as canopy architecture. Better source-sink balance may result from increased partitioning of assimilates during spike development so that grain number is increased; this improves RUE during grainfilling as a consequence of increased demand for assimilates.

Experiments were conducted to determine which of these mechanisms were associated with greater biomass in near-isogenic lines for the *Lr19* gene complex (Table 1) bred as described by Singh et al. (1998) and grown under optimal conditions in Ciudad Obregon, northwestern Mexico, for two cycles between 1998-2000.

Results

Biomass, yield and yield components. Gene *Lr19* was associated with increased yield, above-ground biomass, and grain number in most backgrounds. Averaged over both cycles, the main effect of *Lr19* was a 10%, 8% , and 13% increase in yield, biomass, and grain number, respectively, with the latter coming mostly via increased numbers of grains per

Table 1. Biomass, yield and yield components for *Lr19* isolines in spring wheat backgrounds, averaged over two cycles, Ciudad Obregon, Sonora, Mexico, 1998-2000.

		Biomass (g/m^2)	Yield (g/m^2)	No. grains (per m^2)	Grains / spike	Kernel wt (mg)
Main effect						
Lr19		1,560	670	17,700	44.4	38.3
Control		1,440	610	15,600	39.9	39.4
P level		0.001	0.001	0.001	0.001	0.05
Background	***Lr19***					
Angostura	+	1,575	630	15,500	37.9	40.9
Angostura	-	1,435	585	13,000	36.0	44.9
Bacanora	+	1,495	645	18,700	50.5	34.4
Bacanora	-	1,525	620	17,500	43.0	35.6
Borlaug	+	1,720	755	19,900	48.5	38.2
Borlaug	-	1,520	630	17,300	37.9	36.5
Star	+	1,630	690	18,500	43.9	37.2
Star	-	1,590	640	17,400	39.7	37.0
Seri	+	1,600	675	18,400	47.4	36.6
Seri	-	1,420	630	16,000	45.3	39.6
Oasis	+	1,350	655	15,300	38.4	42.6
Yecora	-	1,180	545	12,700	37.5	42.9
P level (interaction)		0.05	0.05	ns	ns	0.1

spike. Interaction between *Lr19* and background was significant for biomass and yield. In the case of Bacanora, *Lr19* had no effect on biomass and only increased yield by 4%. At the other extreme *Lr19* increased biomass and yield by 14% and 20%, respectively, in Borlaug and Oasis (Table 1).

Radiation interception. The hypothesis that increased yield and biomass associated with *Lr19* may be attributed to improved light interception was tested indirectly by measuring biomass shortly after canopy closure. It was assumed that if significant differences in light interception had occurred they would be reflected in differences in aboveground biomass, but no main effect was found (Table 2). Visual observations of early light interception support this conclusion. Differences in light interception at the end of the season could also account for differences in assimilation rate, but visual assessment of green-leaf area duration between the onset of leaf senescence and physiological maturity revealed no apparent trend.

Radiation use efficiency. Differences in RUE are difficult to assess directly on canopies; however, biomass accumulation over a period of crop growth (when not confounded by differences in light interception or leaf senescence) is probably the best way to estimate RUE. Therefore, in the current study the biomass accumulated shortly after canopy closure(50 d after emergence) and that measured 7 d after flowering (Zadoks-70) was calculated to see whether apparent differences in RUE were associated with improved performance. There was no significant effect of *Lr19* on biomass at either of these early growth stages (Table 2), suggesting that the observed difference in final biomass associated with *Lr19* cannot be attributed to intrinsic differences in RUE. Flag leaf photosynthetic rates measured during booting on all lines indicated no significant main effect of *Lr19* (Table 2) on assimilation rates.

However, biomass accumulation during grainfilling {i.e. between anthesis (Table 2) and harvest (Table 1)} indicated that the main effect of *Lr19* was to increase RUE substantially (by 20%) during this stage. The conclusion is supported by the fact that photosynthetic rate measured on flag leaves during grain filling was 16 % higher for *Lr19* lines (Table 2). Since flag-leaf photosynthetic rate and estimated RUE were not higher before flowering, and that a principal effect of *Lr19* was to increase grain number (Table 1), it is likely that higher photosynthetic rate and RUE measured during grain filling were driven by higher sink strength in *Lr19* lines.

Source-sink balance: Duration of spike growth phase and partitioning to spike. Many wheat scientists believe that yield increases will result from an improved balance between source and sink (Evans, 1993). Although source and sink may co-limit yield, evidence suggests that sinks are more limiting even in modern lines (Slafer and Savin, 1994). Sink strength (i.e., grain number) is determined during juvenile-spike growth; hence this period of development is critical for determining yield potential (Fischer, 1985). Such observations have led to the idea that increasing the relative duration of spike development may, through increasing partitioning of assimilates to the developing spike, increase grain number (Slafer et al., 1996).

Table 2. Main effects of traits related to phenology, partitioning (source-sink), and photosynthesis in near-isogenic lines for the *Lr19* translocation, Ciudad Obregon, Sonora, Mexico, 1998-2000.

Trait	+*Lr19*	Check	P level
Phenology			
Days to terminal-spikelet	42.5	40.5	0.001*
Days to anthesis	86	84	0.001
Days to maturity	124	123	0.001
Relative juvenile-spike growth	35%	35%	ns
Partitioning (source-sink)			
Spike weight 7 d after anthesis (g)	0.775	0.732	0.14
Anthesis harvest index†	0.260	0.243	0.05*
Radiation use efficiency			
Biomass 50d after emergence (g/m^2)	370	390	ns
Biomass 7d after anthesis (g/m^2)	960	940	ns
Photosynthesis-booting (umol m^{-2} s^{-1})	23.9	22.8	ns
Photosynthesis-grainfill (umol m^{-2} s^{-1})	20.9	18.0	0.001

* Interaction between *Lr19* and genotype significant at P = 0.05.

† Anthesis harvest index = dry weight of spike 7 d after anthesis/total culm dry weight.

In the current study *Lr19* isolines were examined for duration of juvenile-spike growth (i.e., between terminal spikelet and anthesis), as well as for relative partitioning of dry matter to spikes. While no differences were found in the duration of spike development, there was a highly significant difference in partitioning of dry matter to spikes, with the main effect of *Lr19* leading to a higher relative investment of total biomass into the spike (Table 2).

Conclusions

Increased yield and biomass of *Lr19* lines resulted from and improved source-sink balance at flowering, which led to higher demand-driven photosynthetic rates during grainfilling. Light interception by the canopy, rates of photosynthesis prior to anthesis , and phenological patterns were not affected by *Lr19* or associated with improved yield and biomass.

Exploiting Genetic Resources to Optimize “Source-Sink” Balance and Improve Stress Tolerance

To boost yield in irrigated situations, it is widely believed that genetic improvement must come from simultaneously increasing both photosynthetic assimilation capacity (i.e., source) as well as improving the partitioning of assimilates to reproductive sinks (Richards, 1996; Slafer et al., 1996). At CIMMYT, a number of traits have been identified with the potential to improve both “source” and “sinks.” Using this information, two types of breeding work are underway: 1) traits are introgressed into good backgrounds to establish potential genetic gains to yield, and 2) “source” and “sink” type traits are crossed together in an attempt to obtain useful synergy with certain recombinations and backgrounds. Other traits are being identified which may be important under stress.

Traits to improve spike fertility (“sink”)

Spike anatomy. Most studies indicate that even in improved germplasm, sink strength is still more limiting to yield than photosynthetic capacity (Slafer and Savin, 1994). Furthermore, studies with *Lr19* isolines (Reynolds et al., 2000) have shown that increased fertility has a direct effect on radiation use efficiency during grainfilling, resulting in higher biomass as well increased grain number and yield. Thus a high priority is to find genetic sources with increased fertility. Traits such as large spikes, branched spikelets (Dencic, 1994) and multi-ovary (Skovmand et al., 2000) are potential sources. Another way to increase grain number would be to increase the intrinsic fertility of the spike by introgressing the multi-ovary floret trait. This objective is being pursued currently in CIMMYT’s Wheat Program. Data for the F1 shows that the trait is expressed better in some backgrounds than others. However, average kernel weight of F1s was in all cases higher than the multi-ovary donor and in many cases higher than both parents, and total grain weight per spike was generally higher than for the parents.

Grain weight potential. Increased yield has been associated considerably more with increased grain number than grain mass (Calderini et al.,1999). In theory, there is no reason why higher grain weight potential, in addition to fecundity of grains, could not increase sink demand and thereby drive both higher yield and biomass. Synthetic wheats have generally larger kernel weights than conventional hexaploid cultivars, and recent work has shown potential for even larger grain mass in synthetic lines when assimilate availability was increased during spike growth (Calderini and Reynolds, 2000). Introgression of high grain weight potential may be expressed if complemented by traits that increase assimilate availability during spike growth.

Phenology. It has been hypothesized that spike fertility may be increased by increasing the allocation of assimilates to spike growth through extending the relative duration of the juvenile spike growth phase of development (Slafer et al., 1996). Genetic variability in duration of juvenile spike growth period is known to exist (Slafer and Rawson, 1994), and germplasm collections have yet to be examined comprehensively to find further variation in the trait. Both grain weight potential and grain number are largely determined during juvenile spike growth phase; hence increasing assimilate availability during this growth stage by extending its duration may create a stronger sink demand resulting from increased potential of both yield components.

Traits to improve assimilate availability ("source")

Genetic progress in improving spike fertility will almost certainly lead to a greater demand for assimilates during grainfilling, and the development of strong sinks may also be partially dependent on a good supply of assimilates during juvenile spike growth. Therefore, photosynthetic capacity will need to be increased in tandem with greater sink capacity. Traits that could be exploited to increase light interception and RUE are discussed below.

Green area duration. There are a number of physiological and morphological traits related to increasing light interception which have yet to be fully exploited in modern wheats and for which genetic diversity appears to exist in germplasm collections. One is the ability to reach full ground cover soon after emergence to maximize interception of radiation. Richards (1996) has developed lines with leaves that have a relatively higher area (as a function of increased embryo size), to achieve this result. Another is the ability to maintain green leaf area duration ("stay-green") throughout grainfilling (Jenner and Rathjen, 1975). In theory, extra assimilates gained by increasing early ground cover could contribute to increased stem reserves and be tapped at later reproductive stages to enhance potential kernel number and size. A longer stay-green period would improve the likelihood of realizing that potential. High intrinsic chlorophyll concentration has also been associated with improved stay-green in sorghum (Borrel, pers. comm).

Genetic diversity for flag leaf chlorophyll has been shown to exist in wheat landrace collections, with some accessions exceeding modern lines such as Seri-82 (Hede et al., 1999). Higher chlorophyll concentration itself could theoretically increase RUE in high radiation environments and has been shown to be associated with yield in modern durum wheats (Pfeiffer, pers. comm.).

Erect leaf. The erect leaf trait has the potential to improve canopy RUE in high radiation environments, since leaves that are exposed perpendicularly to the sun's rays experience supra-saturating light intensity (Duncan, 1971). Germplasm collections were screened for erect leaves at CIMMYT in the early 1970s, and the trait introgressed into the wheat germplasm base from sources such as *Triticum aestivum* ssp. *sphaerococcum*. More erect leaf canopy types are characteristic of many of CIMMYT's best yielding wheat lines (Fischer, 1996). Genetic manipulation of leaf angle is not complex, being controlled by only two to three genes (Carvalho and Qualset, 1978). However, an important question is whether manipulation of leaf angle will permit further gains in RUE. Indirect evidence suggests that the possibility may exist. For example, when comparing two of the highest yielding CIMMYT cultivars Bacanora 88 and Baviacora 92, the former has a partially erectophile leaf canopy, while the latter, which has higher biomass, has lax leaves. We are currently trying to introgress the erect leaf trait into Baviacora.

Traits to improve stress tolerance

A number of traits have been postulated in the literature which may confer stress tolerance in wheat (Figure 1). Not all traits would be useful in all environments. Bearing in mind the specific characteristics of an environment, a conceptual model can be developed for a given target environment encompassing a relevant sub-set of traits. For example, it might be hypothesized that a genotype adapted to a Mediterranean environment with deep soil profiles should have high expression of the following traits: early vigor, stem fructans and biomass at flowering, and high CTD or other water relations parameters during grainfilling, indicating deep roots. The next step would be to identify good sources of these traits and introgress them separately and/or in combination into well adapted backgrounds. CIMMYT's germplasm collection is being screened for sources of these characters; traits will be introgressed into stress tolerant materials and tested in appropriate environments. Populations are currently being developed with diversity for stay-green, peduncle length, and CTD to evaluate potential genetic gains associated with these traits in stressed environments in Mexico.

Using Physiological Tools to Improve Breeding Efficiency

Over the last few years evidence has been accumulating that physiological traits such as stomatal conductance, canopy temperature depression (CTD), and spectral reflectance may have potential to be used as indirect selection criteria for yield. For example, under warm, irrigated conditions, CTD measured on yield trials in Mexico was significantly associated with yield variation *in situ*, as well as with the same lines grown at a number of international testing sites (Reynolds et al., 1994, 1997, 1998). Furthermore, studies with recombinant inbred lines suggest that significant genetic gains can be made in early generations using CTD as an indirect selection criterion.

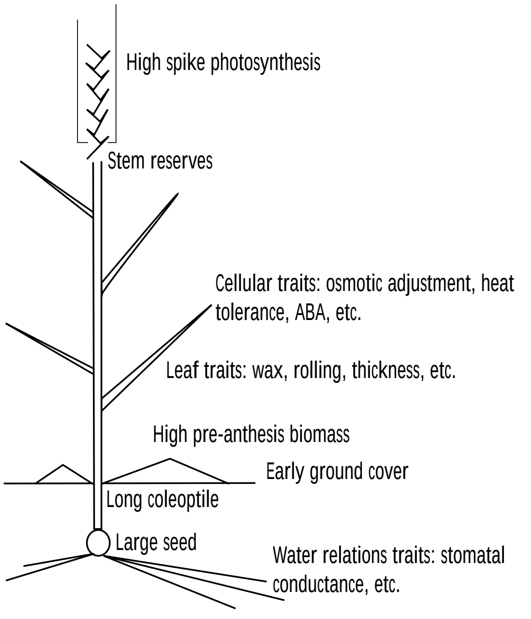

Figure 1. Conceptual model of a drought tolerant wheat plant.

CTD and leaf conductance

Physiological bases of CTD. Leaf temperature is depressed below air temperature when water evaporates from its surface. The trait is affected directly by stomatal conductance, and therefore indirectly by many physiological processes including vascular transport of water, carbon fixation and other metabolic activity. As such, CTD is a good indicator of a genotype's fitness in a given environment. CTD measured during grainfilling seems to be influenced by the ability of a genotype to partition assimilates to yield, since CTD frequently shows a better association with yield and grain number than with total biomass (Reynolds et al., 1997, 1998).

Canopy temperature depression can be measured almost instantaneously using an infrared (IR) thermometer in a small breeding plot. Since the measurement integrates the temperature of several plants at once, the error normally associated with traits measured on individual plants is reduced. Investigations into methodology in warm environments (Amani et al., 1996) have shown that CTD was best associated with performance when measured at higher vapor pressure deficit (i.e., warm, sunny conditions and during grainfilling). Irrigation status was not a confounding factor within the normal frequencies of water application. Similar investigations are being conducted for the temperate environments, and under drought stress. Preliminary data suggest that for irrigated conditions (Figure 2) the protocols recommended for warm environments are appropriate. Under drought, studies were conducted recently to established at what stage of development and at what time of day differences in CTD are most likely to be observed. Measurements were made in the morning and afternoon between full ground cover and late booting, and during grainfilling. Performance seems to be better predicted by CTD measured in the morning during grainfilling or prior to heading (Table 3).

Rapid screening in breeding populations. CTD measured on $F_{5:8}$ recombinant inbred lines from the cross Seri-82 /SieteCerros-66 explained over 40% of the variation in yield (Figure 2). Other work has demonstrated the effectiveness of using the trait in selection nurseries to predict performance of advanced lines in heat stressed target environments (Reynolds et al., 1997, 1998). When CTD was compared with other potential selection traits (grain number, biomass, phenological data, and yield) measured in the selection environment, none of the other traits showed a greater association with performance in the target environment than CTD. The trait was also studied in three populations of homozygous sister lines under drought stress. CTD showed a highly significant association with yield under drought when measured pre-anthesis in all populations. CTD measured during grainfilling tended to show a better association when measured in the morning (Table 3).

In addition to yield, breeding objectives must take into account multiple factors, such as disease tolerance and phenology. Therefore, it would be logical when incorporating CTD into a selection protocol, to select for relatively genetically simple traits such as agronomic type and disease resistance in the earliest generations (e.g., F_2-F_3). Selection for CTD could be employed in subsequent generations, when more loci are homozygous, and perhaps in preliminary yield trials. (Table 4). The possibility of combining selection for both CTD (on bulks) and stomatal conductance (on individual plants) is another interesting possibility. In recent work at CIMMYT (Gutiérrez-Rodríguez et al., 2000), stomatal conductance was measured on individual plants in $F_{2:5}$ bulks and showed significant phenotypic and genetic correlation with yield of $F_{5:7}$ lines.

Aerial infrared imagery. CTD can be estimated remotely using aerial IR imagery. Work conducted in Ciudad Obregon, Sonora, Mexico, showed that aerial IR images had sufficient resolution to detect CTD differences on relatively small yield plots (1.6 m wide). Data were collected using an IR radiation

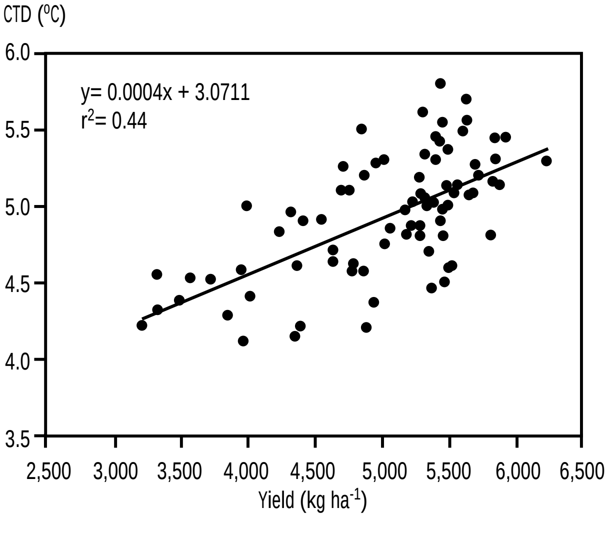

Figure 2. Relationship between canopy temperature depression (CTD) measured during grainfilling and yield of random derived $F_{5:8}$ sister lines from the spring wheat cross Seri-82 x SieteCerros-66, Ciudad Obregon, Sonora, Mexico, 1996 - 1997.
Source: Reynolds et al., 1999.

Table 3. Correlation between CTD measured pre-heading and during grainfilling on 25 recombinant inbred lines of Seri 82 / Baviacora 92, at different times of day, at two environments in Mexico, 1999-2000.

	Correlation with yield	
Trait	C. Obregon (810)	Tlaltizapan
CTD mean	0.85**	0.84**
CTD AM prehead	0.82**	0.79**
CTD AM grainfill	0.79**	0.68**
CTD PM prehead	0.85**	0.72**
CTD PM grainfill	0.37	0.06
Days to maturity	0.29	-0.22

** Statistical significance at P>0.01.

Table 4. Theoretical scheme for incorporating physiological selection criteria into a conventional breeding progam showing different alternatives for when physiological traits could be measured, depending on resources available.

	Breeding generation when selection to be conducted			
Trait	All generations	F3	F4-F6_	PYTs / Advanced lines
Simple traits				
Disease	visual			
Height	visual			
Maturity	visual			
Canopy type			visual	
Complex traits				
Yield			visual	yield plots
CTD			small plots	yield plots
Porometry		plants	small plots	yield plots
Chlorophyll		plants	small plots	*
Spectral reflectance			small plots	yield plots

* Chlorophyll is sufficiently stable with respect to interaction with environment for additional measurements not to be necessary.

sensor mounted on a light aircraft that was flown at a height of 800 m above the plots. Data of plot temperatures showed significant correlation with final grain yield for random derived recombinant inbred lines as well as advanced breeding lines (Table 5). Considering that conditions were sub-optimal at the time of IR imagery measurement (intermittent cloud cover introduced significant error into the measurements), the correlation with yield compared quite favorably with that using hand-held IR thermometers (Table 5).

For both methodologies, correlation with yield were higher with random derived lines than with advanced or elite lines that had already been screened for performance. (This is to be expected since nurseries would be skewed in favor of physiologically superior lines after screening for yield). The results validated the potential of aerial IR imagery as a means of screening hundreds, or potentially thousands, of breeding plots in a few hours for CTD and, hence, for their genetic yield potential.

Spectral reflectance

Sunlight reflected from the surface of breeding plots (spectral reflectance) can be measured with a radiometer and constitutes another potentially useful technique for screening. Spectral reflectance can be used to estimate a range of physiological characteristics including plant water status, leaf area index, chlorophyll content, and absorbed PAR (Araus, 1996). The technique is based on the principle that certain crop characteristics are associated with the absorption of very specific wavelengths of electromagnetic radiation (e.g., water absorbs energy at 970 nm). Different coefficients can be calculated from specific bands of the crop's absorption spectrum, giving a semi-quantitative estimate (or index) of a number of crop characteristics.

In preliminary experiments, the indices NDVI (normalized difference vegetation index), WI (water index), SR (simple ratio) and SIPI (structural independent pigment index) all showed significant correlation with yield, biomass, and leaf area index. The measurements were made during grainfilling on 25 advanced lines selected for diverse morphology, with yields ranging from 5 to 9 t/ha in Obregon. Performance was best correlated with NDVI and was a little higher for biomass (Figure 3) than for yield. Other indices are also being explored; "green NDVI," which we believe will permit better resolution at higher biomass levels, is observed with red NDVI (Figure 3). We are currently evaluating the use of NDVI (red and green) as a rapid screening tool for yield, nitrogen use efficiency, and triticale forage yield.

Table 5. Comparison of canopy temperature depression (CTD) data from aerial infrared (IR) imagery with hand-held IR thermometers, Ciudad Obregon, Sonora, Mexico, 1996-1997.

		Correlation of CTD with yield			
		Aerial		Hand-held	
Trial		Phenotypic	Genetic	Phenotypic	Genetic
RILs (Seri-82 x 7Cerros-66) random derived sisters	81	0.40**	0.63**	0.50**	0.78**
Advanced lines (Bread wheat)	58	0.34**	†	0.44**	†

** Denotes statistical significance at 0.01 level of probability.
† Genetic correlations not calculated due to design restrictions.
Source: Adapted from Reynolds et al., 1999.

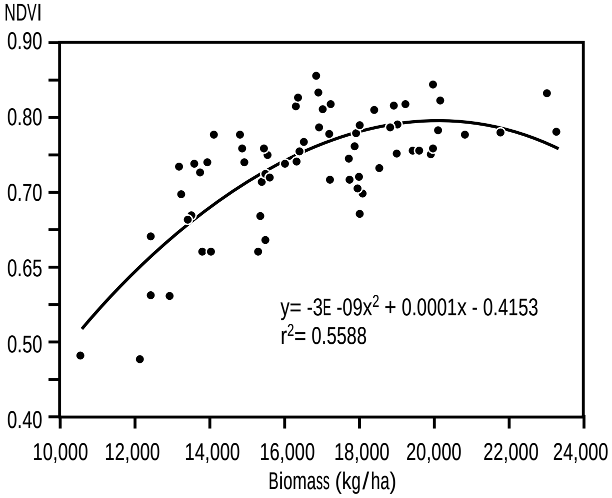

Figure 3. Relationship between spectral reflectance index NDVI (normalized difference vegetation index) measured during grainfilling and biomass of irrigated spring wheat advanced lines, Ciudad Obregon, Sonora, Mexico, 1996 - 1997.
Source: Reynolds et al., 1999.

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CIMMYT Wheat Research and Capacity Building in Eastern, Central, and Southern Africa

D.G. Tanner and T.S. Payne

CIMMYT's activities in Eastern, Central, and Southern Africa are focused on developing broad institutional support for the informal maize and wheat research networks that have evolved over the years. To attain this objective, CIMMYT provides support and guidance to the Eastern and Central Africa Maize and Wheat (ECAMAW) Research Network, operating under the auspices of the Association for Strengthening Agricultural Research in East and Central Africa (ASARECA), and the Maize and Wheat Improvement Research Network (MWIRNET), operating under the auspices of the Southern African Coordination Council for Agricultural Research (SACCAR). Over the past decade, funding for wheat research activities within these networks has been provided by the Canadian International Development Agency (CIDA), the European Union, and the CIMMYT core unrestricted budget.

The Eastern Africa Cereals Program (EACP), funded by CIDA for the past 15 years, has contributed to the enhancement of maize and wheat production throughout Eastern Africa. Over that time, the EACP has enabled researchers from the region to develop and disseminate new crop management practices and varieties to improve maize and wheat cropping. This contribution is important, given that the vast majority of people in the region depend on agriculture for food and cash income. As catalysts for better research and increased farm-level impact in the region, EACP and ECAMAW are involved in the entire range of activities that make a research network truly effective, ranging from research planning, implementation, and budgeting to the training of scientists.

Some Wheat Data for Eastern, Central, and Southern Africa

Total 1994 wheat importation and production in Eastern, Central, and Southern Africa (ECSA) were 4.7 and 2.3 million t, respectively, with a corresponding total wheat area of 2.8 million ha. Annual national wheat production totals ranged from 6,000 t in Uganda, to 1,125,000 t in Ethiopia and 2,321,000 t in South Africa; national wheat areas ranged from 5,000 ha in Uganda, to 750,000 ha in Ethiopia and 1,425,000 in South Africa.

Per capita wheat consumption in the region ranges from a low level of 2.5 kg person^{-1} year^{-1} in Uganda to as high as 75.6 kg person^{-1} year^{-1} in South Africa. In general, during the past decade, per capita consumption has decreased in all countries in ECSA except Ethiopia and Sudan.

The mean regional wheat grain yield of 1.9 t ha^{-1} conceals wide disparities in production potential and performance as influenced by diverse agro-ecological conditions and production systems. On a national basis, mean yields range from 0.8 t ha^{-1} in Burundi to 6.3 t ha^{-1} in Zimbabwe, the highest average wheat yield realized in the developing world. During the 1985-95 period, the rate of increase of wheat yield per hectare was 2.1% year^{-1} in Sudan and 3% year^{-1} in Ethiopia.

Since 1980, 218 wheat and triticale cultivars have been released in ECSA, consisting of 196 bread wheat, 13 durum wheat, and 9 triticale cultivars. Excluding South Africa, cultivars selected and released from CIMMYT-bred introductions and segregating populations accounted for 110 of the 147 cultivars released since 1980 in ECSA. This implies that the national wheat research programs in ECSA rely heavily on CIMMYT wheat germplasm (i.e., 75% of released cultivars are derived directly from CIMMYT germplasm). Regarding germplasm requirements, South Africa is unique in ECSA, with spring and winter types grown, as well as F_1 hybrids. Of the 71 wheat and triticale cultivars released in South Africa since 1980, 40% involved CIMMYT-derived germplasm, 21% were of unknown origin (i.e., the parentage of commercial F_1 hybrids), with the remaining releases—primarily winter habit types—utilizing non-CIMMYT germplasm.

Diseases Prevalent in ECSA

In recent years, yellow rust has supplanted stem rust as the rust pathogen of primary concern in ECSA. Over the past ten years, single step mutations have resulted in the evolution of new virulences in the yellow rust pathogen in Kenya, demonstrating the danger of breeding for race-specific resistance. From 1969 to 1989, at least 19 races were identified. In August 1996, yellow rust was observed for the first time in South Africa, and within a year, the disease had spread to most wheat producing areas in the country. Infected grass species serving as accessory hosts were also observed in the Western Cape and Eastern Free State, with “6E16” identified as the originating race. MWIRNET/RSA is currently sponsoring a germplasm shuttle breeding program whereby South African wheat germplasm is screened for resistance to yellow rust in a location in southwestern Uganda considered to be a global hot-spot for this pathogen.

CIMMYT is also supporting distribution of a Sub-Saharan Wheat Disease Monitoring Nursery. This nursery is intended to validate regional varietal disease performance while monitoring potential performance criteria important for farmers and NARS cooperators throughout East, Central, and Southern Africa.

Septoria nodorum, *S. tritici* and *S. avenae* f.sp. *triticeae*, loose smut, scab, root rot, take-all and *Helminthosporium* spp. cause significant yield losses in ECSA. Cereal aphids (*Schizaphis graminum*, *Rhopalosiphum padi*, *R. maidis*, *Sitobion avenae* and *Diuraphis noxia*) can also be major pests of wheat in this region, and several species serve as vectors in the transmission of barley yellow dwarf virus. Yield losses of up to 47% due to BYDV have been reported in Kenya. Yield losses of >60% due to *D. noxia* have been reported in South Africa, and, at present, all bread wheat cultivars grown in the summer rainfall zone of RSA require genetic resistance to this pest. MWIRNET/RSA is currently supporting research to identify an indicator capable of differentiating *Dn* resistance genes by assessing differences in aphid feeding behavior.

Industrial Quality

The free-market, global economy promotes the production and consumption of the lowest cost products. Throughout ECSA, however, limited and unscientific information (i.e., market biased) is available on the relative milling and baking quality of nationally produced wheat. ECAMAW and MWIRNET have promoted Regional Industrial Quality Cooperative Testing Trials to enable regional wheat breeders, producers, processors, and grain marketing organizations to better understand the inherent milling, baking, and nutritional quality aspects of advanced germplasm and cultivars.

Agronomic Research

A special feature of the ECAMAW collaboration is agronomic research targeted at farm-level problems that must be resolved to promote long-term agricultural productivity in the region. Wheat crop production recommendations that have recently been provided to extension services due to ECAMAW research activities include:

- The semidwarf bread wheat cultivars HAR604 (“Galama”) and HAR1685 (“Kubsa”) recently released in Ethiopia exhibit the highest productivity and profitability across a range of crop management systems, and result in the highest marginal rates of return under increased input levels. The profitability of bread wheat production in the central highlands of Ethiopia can be markedly increased by focusing the application of improved crop management practices on these specific cultivars.

- Pendimethalin plus bromoxynil plus MCPA offer effective control of the major grass (*Sorghum arundinaceum* and *Echinochloa colona*) and broadleaf weeds (*Zelya pentandra*, *Portulaca oleraceae* and *Corchurus olitorius*) in irrigated wheat in the Awash Valley of Ethiopia. A combination of these three chemicals effectively controlled both grass and broadleaf weeds and significantly increased grain yield.
- Economic optimum rates of N and P fertilizer for the high-yielding semidwarf bread wheat HAR1685 ("Kubsa") were determined under the improved drainage technology known as broad bed and furrow (BBF) in Ethiopia. Under two contrasting cost/price scenarios, partial budget analysis indicated that 138-46 kg N-P_2O_5 ha^{-1} was the most profitable of the nutrient combinations tested.
- In Ethiopia, faba bean was recommended for a three-year crop rotation with wheat. The rotation improves wheat grain yield by as much as 65% in year 1 and 35% in year 2, enhances wheat response to phosphorus fertilizer, fixes as much as 210 kg ha^{-1} of nitrogen, and improves soil nitrogen balances by almost 65 kg ha^{-1} of nitrogen. The research service has established demonstration plots for the technology, which is also being promoted by the national extension program.
- Higher N application rates recommended for bread wheat in Ethiopia provide a return on the investment in fertilizer in excess of 300% and an additional 12 kg grain for each kg of N applied. Interestingly, in Vertisol zones in Ethiopia, the N application exhibited a residual benefit in year 2 equivalent to 40% of the response seen in year 1. The new N recommendations have been disseminated by the national bread wheat extension effort and through Sasakawa Global 2000. Urea use on wheat rose sevenfold between 1994 and 1998, and national wheat production rose by over 40% during the same period.

Technologies in the pipeline include:

- Economic analysis of long-term crop management trials, essential to the interpretation of the agronomic results, is being targeted for analysis and summarization.
- Competition effects of three broadleaf weed species (*Guizotia scabra, Amaranthus retroflexus* and *Galium spurium*) on the grain yield of bread wheat have been studied in Ethiopia; economic thresholds for herbicidal intervention in relation to weed seedling density have been determined.
- Twenty genotypes of bread wheat, previously selected for high grain yield potential under weed-free conditions, are being tested for yield potential under competition with *Avena sativum* (as a proxy for grass weeds).

Technology Dissemination

Within the ECSA region, the Kulumsa research center of EARO, Ethiopia is widely recognized as a center of excellence for bread wheat research. This center actively collaborates in the regional networks; thus, a study was initiated in collaboration with CIMMYT's Natural Resources Group to identify the specific areas within ECSA for which the transfer of materials, technologies, or information to and from Kulumsa would be appropriate. Climate similarity maps contained within the Africa Maize Research Atlas were used to address this question at the regional level.

The results highlighted the climatic similarity of Kulumsa to most of the major wheat producing regions in Eastern Africa (Figure 1), and supported

Figure 1. Climate similarity map for the Kulumsa Research Center, Ethiopia.

the pivotal role of Kulumsa in the regional networks. One surprise finding was that a significant area in eastern South Africa exhibited climatic similarity to Kulumsa, yet this is not a wheat producing region. This prompted an investigation into what additional factors were involved in this particular region. It was discovered that several factors were involved, including difficult terrain, wheat not being a crop of choice for traditional smallholders, and high levels of commercial production in southwestern areas. This highlights the fact that factors, including socio-economic issues, must also be considered when examining crop distribution.

Empowering Women Farmers

Another important aspect of EACP and ECAMAW is an emphasis on empowering the region's women farmers as well as sensitizing the researchers (male and female) who work on their behalf. The importance of women to Africa's agricultural economy is indisputable, but many researchers and extension workers have not previously received training in methods that would ensure that research benefits female producers. To address this problem, ECAMAW launched a series of gender analysis and training initiatives in concert with the Centre for Women's Studies and Gender Analysis, Egerton University, Kenya. Over the last three years, these initiatives have included:

- Participation of the ECAMAW steering committee in a gender orientation training session.
- A course entitled "Training of trainers in gender analysis and planning for the ECAMAW research network" empowered researchers to conduct gender analysis training for colleagues in their respective national programs.
- Of the 228 people included in ECAMAW-sponsored training activities during 1997-1999, 49 (21.7%) were women—more than the proportion of female scientists (15.3%) in national maize and wheat research programs in the region.
- Reflecting an initiative to empower women scientists, women researchers led 28 experiments funded by the network's small grants program during 1997-1999.
- More studies on gender issues in agriculture are being undertaken. During 1998, the network funded a synthesis of farm-level survey information generated in four countries, highlighting the roles of women in maize and wheat cropping systems and identifying research domains requiring gender-differentiated approaches. Since 1997, six studies on the adoption of technologies, including the collection of gender-disaggregated data, have been funded by the network's small grants program.
- All research proposals submitted to ECAMAW's small grants program are required to include an analysis of the gender dimensions and implications of proposed technological interventions.
- More than 25 research proposals funded each year by this program have included a gender analysis component.
- Under the small grants program, 31 projects have examined issues that are significant to women farmers (e.g., evaluation of technologies for soil fertility management; the effects of green manure and cropping sequences on soil fertility; the role of drought tolerant legumes in cereal production systems; participatory evaluation of bread wheat technologies; on-farm evaluation of integrated crop management practices for weed control; and informal seed production, distribution, and diffusion for resource poor farmers).

Chinese Wheat Production and the CIMMYT-China Partnership

He Zhonghu[1]

Wheat Production and Challenges

Wheat is the second most important crop in China. During the 1996-2000 period, on average, Chinese wheat area was 29.1 million ha, yearly production 112 million tons, and yield 3,850 kg/ha. Compared with the 1991-95 period, the wheat area decreased by 2.0%, but production and average yield increased 10.7% and 12.9%, respectively. However, Chinese wheat industry faces great challenges with its upcoming entrance into the World Trade Organization (WTO). Thus Chinese wheat needs to compete successfully on the international market and with other crops on the domestic market.

Key to achieving sustainable wheat production in China are 1) improving wheat yield potential and industrial quality; 2) reducing the use of inputs such as irrigation water and fertilizer, 3) protecting the environment (for example, by reducing pesticide use); and 4) increasing wheat production efficiency and profitability. Also important is the increased incidence of wheat diseases. For example, due to the breakdown of yellow rust resistance in Fan 6 and its derivatives, there have been epidemics of yellow rust in southwestern China almost every year since 1996. Also, sharp eyespot and take-all have become major problems, while control of powdery mildew and head scab still needs to be strengthened.

Wheat quality has been a limiting factor because most Chinese wheat varieties were selected based on yield performance. The Chinese Government has eliminated the protected price system in Yangtze and other spring wheat regions where wheat quality is poor; consequently, the wheat area in the 1999-00 season was reduced by 1.6 million ha compared with the 1998-99 season. Wheat prices hit a historic record low (US$ 95 to 120 per ton), causing farmers to start growing other crops. However, contract production has been encouraged, and the milling industry is allowed to buy wheat directly from farmers, who usually receive premium prices for good quality wheat.

Wheat trade organizations in USA, Canada, Australia, and EU are pressing China to increase wheat importation. Multinational companies such as Monsanto and Limargain have initiated their wheat efforts in China. Therefore, CIMMYT must work closely with Chinese wheat programs to provide technical support for the sustainable development of the wheat industry. Progress on CIMMYT-China joint activities are presented in this report.

Wheat Quality Improvement

A wheat quality laboratory has been jointly established by the Chinese Academy of Agricultural Sciences (CAAS) and CIMMYT. Major activities include germplasm introduction, testing, and distribution, standardization of the quality testing system, investigation of genotype and environment interaction on major quality traits across China, noodle and steamed bread quality, soft wheat quality, milling quality, genetics and molecular markers for quality traits, training, and international cooperation. The research programs are supported by the Chinese Ministry of Agriculture, the National Natural Science Foundation of China, GRDC, CIMMYT, and CAAS.

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Regional wheat quality classification

A wheat quality map for China will be constructed based on climate data (temperature, rainfall), soil type, farming system, fertilizer use, and quality data collected in China over the last 15 years. The official document will be finalized and released in 2001. To date, three regions have been recognized:

- Winter and facultative wheat region (Zones I and II); hard white and medium-hard types for making bread, noodles, and steamed bread.
- Autumn-sown spring wheat region (Zones III, IV, and V); soft red type, but also medium-hard red type for steamed bread and noodles. Sprouting tolerance needed.
- Spring-sown spring wheat region (Zone VI, VII, and VIII); hard red and medium-hard types for making bread, steamed bread, and noodles. Sprouting tolerance needed.

Noodle quality

Noodles and steamed bread are the major wheat products consumed in China. However, laboratory testing procedures for the required quality have not yet been established, which limits quality improvement efforts. One hundred four varieties and advanced lines were sown in two locations in the 1997-98 and 1998-99 crop seasons, respectively, to investigate the association between wheat quality traits and the quality of dry white noodles and to identify wheat varieties conferring good noodle making quality. Major results are presented in Table 1.

Grain hardness, water absorption rate, and tolerance index have a significant negative association with noodle quality, while protein content, SDS sedimentation value, stability, extension area, and peak starch viscosity have a significant positive association with noodle quality (Table 1). Therefore, medium hardness, high whiteness, medium protein content, medium to high gluten strength, good extensibility, and high starch peak viscosity are desirable for good noodle quality. Eight Chinese wheat varieties (Ph82-2-2, Zheng 81-1, Lu 955159, Wenmai 6, Shaanyou 225, Lu 935031, Yangmai 5, and Zhongyou 9507) and five Australian varieties (Eradu, Sunstate, Hartog, Cadoux, and Gamenya) were identified to confer good noodle quality. It is also possible to develop varieties combining good bread and noodle quality; Sunstate, Hartog, Lu955159, and Zhongyou 9507 are good examples. A laboratory method for evaluating noodle quality has also been established.

Steamed bread quality

Seventy-eight wheat varieties were sown in the 1997-98 and 1998-99 crop seasons to investigate the association between wheat quality traits and the quality of northern-style steamed bread, and to identify varieties conferring good steamed bread making quality. The major results are presented in Table 2.

Protein content, gluten strength, and extensibility are positively correlated with steamed bread volume and elasticity, but negatively associated with appearance when manual procedures were used (Table 2). Therefore, quality requirements for steamed bread will depend largely on the processing procedure. Weak to medium gluten type is desirable for making steamed bread by hand, while medium to strong gluten type will produce

Table 1. Correlation coefficients between wheat quality traits and noodle quality parameters.

Traits	Color	Appearance	Palate	Elasticity	Sticki-ness	Smooth-ness	Taste	Total score
Hardness	-0.39**	-0.30**	0.11	0.00	-0.07	-0.31**	-0.35**	-0.13
Whiteness	0.54**	0.46**	0.00	0.16	0.27**	0.39**	0.55**	0.34**
Protein content	-0.14	-0.12	0.22	0.28**	0.19*	-0.16	-0.12	0.17
SDS sedi.	-0.02	0.00	0.35**	0.56**	0.48**	0.00	0.27**	0.46
Water absorption	-0.41**	-0.34**	-0.01	-0.19	-0.24*	-0.42**	-0.48**	-0.31**
Stability	-0.02	0.01	0.21	0.50**	0.45**	0.01	0.23*	0.39**
Tolerance index	-0.06	-0.10	-0.36**	-0.58**	-0.48**	-0.10	-0.28**	-0.54**
Extension area	-0.15	-0.10	0.30**	0.58**	0.46**	-0.06	-0.11	0.40**
Peak viscosity	0.31**	0.28**	0.13	0.39**	0.34**	0.24*	0.50**	0.41**

N = 104; correlation coefficients were calculated based on two locations/two years average.

* and ** indicate significance at 5% and 1% probability level, respectively.

good steamed bread using mechanized processing. Good flour whiteness and high peak viscosity contribute positively to the desirable color of steamed bread. However, 16 varieties (6 with strong gluten, 5 with medium gluten, and 4 with weak gluten) were identified to confer good steamed bread making quality using both procedures. It is possible to develop varieties combining good bread and steamed bread quality; Jinnan 17 is a good example. This also indicates that further work is needed to better understand steamed bread making quality.

Table 2. Correlation coefficients between wheat quality traits and the quality of northern-style steamed bread.

Traits	Volume	Appearance	Color	Structure	Elasticity	Stickiness	Total score
Hardness	[a]0.45**	-0.19	-0.22	0.33**	0.36**	0.13	0.27*
	[b]0.16	0.02	-0.21	0.22	0.07	0.16	0.09
Whiteness	-0.39**	0.10	0.41**	-0.32*	-0.33**	-0.26*	-0.29*
	0.00	-0.03	0.39**	-0.24*	0.05	-0.05	0.01
Protein content	0.45**	-0.29*	-0.19	0.15	0.33**	-0.06	0.15
	0.28*	-0.18	-0.08	0.09	0.13	0.11	0.05
SDS Sed.	0.39**	-0.22	0.12	0.15	0.42**	-0.03	0.26*
	0.53**	0.05	0.12	0.21	0.39**	0.28*	0.39**
Water absor.	0.33**	-0.08	-0.17	0.19	0.29*	0.13	0.18
	0.05	-0.10	-0.23	-0.02	-0.19	-0.07	-0.15
Stability	0.20	-0.44**	0.07	-0.06	0.24*	-0.28*	-0.09
	0.57**	-0.03	0.26*	0.03	0.46**	0.29*	0.33**
Extension area	0.25*	-0.50**	0.10	-0.07	0.21	-0.36**	-0.10
	0.51**	-0.07	0.23	0.05	0.37**	0.32**	0.30*
Peak viscosity	-0.16	0.03	0.51**	0.15	0.27*	0.37**	0.32*
	0.17	0.09	0.30*	-0.12	-0.09	0.03	0.09

[a, b] Correlation coefficients derived from manual and mechanized procedures, respectively, in the 1998-99 season.
* and ** indicate significance at 5% and 1% probability level, respectively.

Shuttle Breeding and Germplasm Exchange

More than 35 Chinese institutes receive CIMMYT wheat international nurseries annually. CIMMYT wheat could be used directly in the spring wheat region, particularly in Xinjiang and Yunnan. Outstanding germplasm selected for the last several years is presented in Table 3.

CIMMYT wheat has been extensively crossed with Chinese wheats; leading varieties derived from CIMMYT wheat are presented in Table 4.

Regional wheat screening nurseries have been established, and five sets of screening nurseries were distributed to wheat programs in China. Details are presented in Table 5.

Table 3. CIMMYT germplasm showing outstanding performance in China.

Name / Cross	Location
Ningmai 10 (SHA 7/PRL"s"//Vee 6) CM 95117	Jiangsu, released variety
E001 (ATTILA)	Yunnan, released variety
S001 (unknown)	Yunnan, leading variety
R 101 (AGA/4*HORKS)	Yunnan, leading variety
Milan	Sichuan
NG8319//SHA4/LIRA	Yunnan
WEAVER/LACANA	Yunnan
ATTILA/3/HUI/CARC//CHEN/CHTO/4/ATTILA CMBW90M4860	Gansu
CHIL/2*STAR CM12793-0TOPY	Gansu
URES/BOW//OPTA CM100946-10Y-030M	Gansu
Kehong 16 CM95434	Heilongjiang

Table 4. Outstanding quality of wheat varieties derived from CIMMYT germplasm.

Variety	Major trait	CIMMYT germplasm	Type / Location
Zhongyou 9507	bread/noodle quality	Yecora F 70	W*/Zone I
Jinan 17	bread/steamed bread	Saric F70	F/Zone II
Shandong935031	noodle quality	Saric F70	F/Zone II
Chuanmai 30	rust resistance	Genaro 81	S/Zone IV
Liaochun 10	bread quality	Mexipak 66	S/Zone VI
Ningchun 4	bread quality	Sonora 64	S/Zone VIII
Yunmai 39	drought tolerance	Flicker"s"	S/Yunnan
Xinchun 6	high yielding	Siete Cerros	S/Xinjiang

W= winter wheat, F= facultative wheat, s= spring wheat.

Wheat Agronomy: The Bed Planting System

The area planted using the bed planting system in China was 600 ha in 2000. The system benefits both the wheat and maize crops in a wheat-maize rotation. Bed planting has several advantages over the traditional system: ease of planting, labor-saving, 15-20 cm plant height reduction and improved lodging resistance, fewer diseases, easy application of fertilizer and irrigation, and yield increases of 10-15%. However, the lack of small machines for family use limits the popularity of this

Table 5. Regional screening nurseries distributed by CIMMYT-CAAS in China.

Type	Line number	Location / Institute
Winter and facultative wheat observation nursery	70-80	35
Quality wheat observation nursery	50	40
South China winter wheat observation nursery	20	10
Spring wheat observation nursery	35-40	12
CIMMYT wheat quality observation nursery	30	14

technology, although big machines are available in Heilongjiang Province.

Training and Information Exchange

CIMMYT and CAAS have jointly organized wheat breeding meetings and training courses as presented below. These events have greatly enhanced the scientific exchange between CIMMYT and Chinese wheat breeding programs.

- CAAS-CIMMYT Wheat Breeding Meeting, Beijing, 1995
- China-CIMMYT Wheat Breeding Meeting, Henan, 1997
- China-CIMMYT Wheat Quality Training Course, Beijing, 1998
- China-CIMMYT Spring Wheat Breeding Meeting, Inner Mongolia, 1999
- China-CIMMYT Wheat Quality Training Course, Beijing, 1999
- National Wheat Breeding Meeting, Shandong, 2000
- International Scab Symposium(co-sponsor), Suzhou, 2000
- GxE training course for multi-location data analysis, Beijing, 2000

In 1997-2000, seven MSc students did their thesis work at the CAAS-CIMMYT quality lab. Currently, there are 10 postgraduates working on wheat quality, powdery mildew, yield potential, and molecular markers.

The following CIMMYT publications have been published in Chinese. CIMMYT also published three wheat special reports on Chinese wheat.

CIMMYT publications in Chinese:

- Zou Yuchun (translator), 1994. Collection of CIMMYT Wheat Breeding Papers. Sichuan Science and Technology Press.
- He Zhonghu (translator), 1995. CIMMYT Wheat Breeding Methodology. China Agrotech Press.
- Yang Yan (translator), 1999. Bunt and Smut Diseases of Wheat: Concepts and Methods of Disease Management. Wilcoxson R.D., and E.E. Saari, eds. China Agrotech Press.
- He Zhonghu (translator), 1999. Increasing Yield Potential in Wheat: Breaking the Barriers. Reynolds, M.P., S. Rajaram, and A. McNab, eds. China Science and Technology Press.
- Sun Jiazhu (translator), 2000. CIMMYT 1998-99 World Wheat Facts and Trends. Global Wheat Research in a Changing World: Challenges and Achievements. Beijing Academy of Agricultural Sciences.

CIMMYT publications on Chinese wheat:

- He Zhonghu and Chen Tianyou. 1991. Wheat and Wheat Breeding in China. CIMMYT Wheat Special Report No 2.
- Yang Zouping. 1994. Breeding for Resistance to Fusarium Head Blight of Wheat in the Mid- to Lower Yangtze River Valley of China. CIMMYT Wheat Special Report No 26.
- He Zhonghu and S. Rajaram. 1997. China/ CIMMYT Collaboration on Wheat Breeding and Germplasm Exchange: Results of 10 Years of Shuttle Breeding (1984-94). Proceedings of a conference held in Beijing, China, July 3-5, 1995. CIMMYT Wheat Special Report No. 46.
- He Zhonghu, S. Rajaram, Xin Zhiyong, and Huang Jizhang. 2000. Chinese Wheat Breeding and varieties pedigrees (in press).

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Liu Aihua. 2000. Investigation on the association between wheat quality traits and the performance of northern-style Chinese steamed bread. MSc Thesis, CAAS.

Liu Jianjun. 2000. Investigation on the association between wheat quality traits and the performance of Chinese dry noodle quality. MSc Thesis, CAAS.

Z. He, M. van Ginkel, and S. Rajaram. 2000. Progress of the China/CIMMYT cooperation on shuttle breeding and germplasm exchange aimed at combining high yielding potential with resistance to scab. Proceedings of the international symposium on wheat improvement for scab resistance. pp. 157-160.

Improving Wheat Production in Central Asia and the Caucasus

A. Morgounov, M. Karabayev, D. Bedoshvili, and H.-J. Braun

The countries of Central Asia (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan) and the Caucasus (Armenia, Azerbaijan, and Georgia), with a population of 62 million people, produce 15-16 million tons of wheat a year. The wheat-growing environment is divided into two distinct regions (Figure 1). The Southern region (36-44ºN latitude), occupying 5-6 million ha across all eight countries, grows fall-planted winter or facultative wheat mostly under irrigation (60-70%) The main crops are cotton, sugar beet, maize, and vegetables. Rainfed wheat is planted on the other 30-40% of the area, mostly on hillsides or mountains where irrigation is not possible. The major biotic constraint for wheat production is yellow rust, which has affected the region in the last 3-5 years. Yield potential in the best irrigated fields (Fergana Valley, Chui Valley, and Samarkand) is close to 5-6 t/ha. However, average yield barely reaches 2 t/ha due to poor agronomy and lack of inputs.

The Northern region (48-52ºN latitude), 10-11 million ha located only in Kazakhstan, grows spring planted spring wheat with daylength sensitivity. There is a comparable wheat area in Russian Siberia across the border. Though this area is not part of CIMMYT's mandate, the similarity of environment and strong traditional links between researchers suggest that activities in the North should involve both Kazakhstan and Siberia. Wheat is the principal crop in this region, where it is rotated with fallow every 3-4 years. It is planted in May and harvested in August. Drought represents a major abiotic stress. Septoria, leaf rust, and root rots are the major diseases in the region.

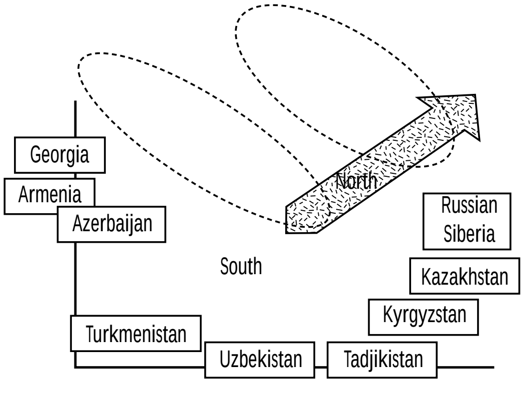

Figure 1. Map of major wheat-producing regions in Central Asia and the Caucasus.

History of CIMMYT Cooperation in CAC

CIMMYT cooperation with Central Asia and the Caucasus (CAC) goes back to the time when this region was part of the Soviet Union. In the 1970s there was a substantial flow of Mexican germplasm to the USSR and wide-scale testing of new wheat varieties in all agroecological environments. Bread and durum wheats (Siete Cerros and Oviachik 66) that proved competitive were released in areas with mild winters (southern Russia, Azerbaijan, Uzbekistan, and Tadjikistan). At the same time, many lines were used in crosses, and a number of modern wheat cultivars in the region have Mexican germplasm in their pedigrees.

The initial dynamic germplasm exchange of the 1970s was followed by a pause in the 1980s, when the germplasm was channeled through the Vavilov Institute in St. Petersburg; usually it was delayed or never reached the breeding programs. In the 1990s interest in collaborating with the region was renewed as the newly independent states were able to establish direct linkages with CIMMYT. After independence, research programs found themselves isolated and in need of new and better sources of germplasm, methodologies, and information.

In 1992-93 the CIMMYT office in Turkey working on winter wheat in cooperation with Turkey and ICARDA initiated germplasm exchange and supplied several nurseries to the key breeding programs in CAC, as well as Russia and the Ukraine. In 1994-95 the first exchange visits by scientists facilitated establishing better cooperation and defining priorities. Since 1996-97 germplasm exchange and visits by scientists have become routine.

In 1998 USAID for the first time donated funds targeted to the region. The same year Nobel Laureate Dr. Norman E. Borlaug and Dr. S. Rajaram, CIMMYT Wheat Program Director, visited Kazakhstan and reached an agreement about establishing a CIMMYT regional office there. In 1999 the CGIAR allocated restricted funds for cooperation with CAC, and a CIMMYT office was opened in Almaty, Kazakhstan. Later in 2000 the President of Kazakhstan signed a law "On the cooperation between the Republic of Kazakhstan and CIMMYT in agricultural science," thus giving high official recognition and status to CIMMYT in Kazakhstan. Since 1998 the program has undergone dynamic evolution and expansion.

Program Structure and Objectives

Since 1995-96, when the program for CAC was being formulated, CIMMYT recognized the following features of the region: relatively high potential of local scientists, isolation from the global scientific community in terms of scientific information and language, lack of a targeted research approach that takes into account farmers' interests, deteriorated infrastructure and machinery in research programs, little regard for sustainability in agricultural development, and great interest in cooperating with international centers.

Though providing farmers with improved technologies was considered important, equally important was building NARS capacities to perform efficient research. Thus the objectives of the CIMMYT program in CAC are 1) sustainable improvement of wheat-based cropping systems through better technologies; and 2) improvement of wheat research efficiency through more targeted research programs, improved methodologies, newer machinery, and operational support. The structure of the program, its themes, and funding are shown in Table 1.

Winter Wheat Breeding

Although winter wheat occupies only 30% of the total wheat area in the southern region, its importance cannot be overestimated. Winter wheat is grown in highly populated areas, and its area has increased three- to five-fold after independence, as governments strive for self-sufficiency in grain. Winter wheat remains a prime source of subsistence food in rural areas of most CAC countries. Traditionally, winter wheat breeding programs were stronger in Kazakhstan and Kyrgyzstan. Before 1991 wheat was a minor crop in Tadjikistan, Turkmenistan, and Uzbekistan and, therefore, their breeding programs were less advanced.

There is a rich diversity of wheat wild relatives in the Caucasus, where good basic and applied wheat research has been conducted. In view of this diversity, it was interesting to observe what the performance of international winter wheat germplasm would be. The first nurseries shipped to the region from Turkey (4th and 5th FAWWON) numbered 300 lines and contained only 10-15 g of seed. Within two years it was obvious that some of the lines selected from these nurseries competed well not only with local checks but also with the best new lines/varieties.

Table 1. Structure of the CIMMYT program in CAC, 2000-2001.

	Germplasm development				General / Economics	
Activity / Country	Winter wheat	Spring wheat shuttle	Seed production	Agronomy / On-farm activities	Economic analysis	Consulting NARS
Armenia	X			X	X	
Azerbaijan	X			X	X	X
Georgia	X			X		
Kazakhstan	X	X	X	X	X	X
Kyrgyzstan	X			X	X	
Tadjikistan	X		X	X		
Turkmenistan	X			X		
Uzbekistan	X		X	X	X	X

Good performance of international germplasm in CAC and the demand from local breeders resulted in a substantial increase in the germplasm provided from the Turkey-CIMMYT-ICARDA program in Ankara and from CIMMYT-Mexico. Since 1998 eight different winter/facultative wheat nurseries, supplemented by several spring wheat nurseries from Mexico, have been offered to regional programs. By 2000 approximately 4000 entries had been delivered to the region. Local breeders have done a tremendous job of screening and selecting promising lines suited to local conditions. International germplasm became the only source of genetic variability and varieties in some countries; in others, lines selected from international nurseries created healthy competition with local germplasm for direct utilization on farmer's fields and were excellent choices as parents for crosses.

Table 2 gives a sample of the performance of a few lines introduced in the region. Introduced germplasm has three major advantages over local materials: broad adaptation, high yield, and resistance to yellow rust. It may, however, be inferior in industrial quality. Durum wheat and triticale introduced from Mexico also performed extremely well and are in high demand, since there are only a few breeding programs working on these crops.

Several other important developments include establishment of CAC-WWINET, a winter wheat network linking researchers in the region, to more efficiently address common problems and establish better communication channels. An experiment was launched to test what growth habit is more suitable for the region. Preliminary data of field tests show that isogenic lines with winter growth habit have an advantage over spring types. Some countries participate in the Winter Wheat East European Yield Trial and have direct access to elite germplasm from eastern Europe and the USA. For the first time after the break-up of the USSR, systematic monitoring of yellow rust and disease surveys have begun.

Table 2. Agronomic performance of winter wheat lines selected from international nurseries in CAC.

Country	Line	Trial type, year	Yield t/ha	% to LC	YR %
Armenia	SN64//SKE/2*/ANE/3/SX/4/BEZ/SERI	On-farm, 1999	8.2	157	20
Azerbaijan	Prinia (Azamatly 95)	On-farm, 1997-00	7.7	122	10
Georgia	NS55-58/VEE	Official, 1997-99	4.8	111	5
Kazakhstan	BHR/AGA//TRK13	On-farm, 2000	5.0	133	10
Kyrgyzstan	F10S-1	YT, 2000	5.5	119	R
Tadjikistan	PYN/BAU	Official, 2000	3.3	112	10
Turkmenistan	SN64//SKE/2*/ANE/3/SX/4/BEZ/SERI (Bitarap)	YT, 1999-2000	5.3	100	20
Uzbekistan	YMH/TOB//MCD/3/LIRA (Dustlik)	On-farm, 2000	5.9	108	15
	ARMINO (Norman)	YT, 1997-99	8.7	161	R

Spring Wheat Breeding

Wheat varieties grown in northern Kazakhstan are similar in height, type, and spike morphology, and possess good drought tolerance and excellent grain quality. However, most of them are highly susceptible to leaf rust and septoria leaf blotch, two major diseases prevalent in the north in wet years. The leaf rust epidemic of 2000 demonstrated that none of 80 tested modern varieties and breeding lines from Kazakhstan and Russia are resistant to the pathogen.

Priorities for cooperation in the region were identified during a joint Kazakhstan/CIMMYT spring wheat conference in 1997. In developing spring wheat varieties the challenge is to combine the drought tolerance and good grain quality of local materials with disease resistance from Mexican germplasm in a daylength-sensitive background. Shuttle breeding seemed most appropriate for achieving this, because CIMMYT's subtropical location limits full-scale development of daylength-sensitive germplasm. The first crosses were made in 1998 and the resulting populations went through several cycles of selection for tall stature, disease resistance, and daylength-sensitivity under artificial light. The first lines from this program will be sent to Kazkahstan and Siberia in 2001 to be selected under local conditions for one to two years. The best lines selected under drought in Kazkahstan and Siberia will be utilized locally and sent to Mexico for the next cycle of crosses and selection.

In addition to shuttle breeding several activities are conducted in the framework of the Kazakhstan-Siberia Network (KASIB Network) on spring wheat improvement with similar objectives. At the second meeting of the network in Barnaul, Russia, in 2000, several breeding programs indicated their willingness to join the network, which, as a result, will be expanded and formalized in 2001.

Agronomy

Until now regional cooperation on agronomy has been limited to on-farm promotion of locally developed wheat technology components to improve yield and profitability based on realistic costs of inputs and field operations. In the winter wheat areas of Kazakhstan two years of experimentation showed that high seeding rates (220 kg/ha) used by farmers are not justified. There was no yield increase compared to using 120 kg/ha. At the same time yield increase due to fertilizer use improved the profitability of grain production per unit area. Similar experiments in northern Kazakhstan proved the importance of variety, seeding dates, and the preceding crop. Future priorities for northern Kazakhstan will be developing and testing zero-tillage, which is vital in a region prone to wind erosion. In the irrigated areas of the South, efforts will focus on adapting bed planting and new irrigation techniques.

Improving Research Efficiency

Helping NARSs improve their research efficiency—above all, through training—is one of the prime goals of the CAC program. A number of national and regional training courses have been conducted over the last two years. Topics varied from the very specific (use of the computer in breeding, on-farm trials, seed production, etc.) to the more general (agronomy, English language). The best young scientists attend training courses in Mexico.

CIMMYT has been helping organizations such as the World Bank, the Asian Development Bank, and GTZ (Germany) to evaluate the agricultural research and cereals production sector and draft plans for change and reform. In 2000 the CIMMYT team started a two-year project that will lead to the establishment of a competitive grant system for funding agricultural research in Azerbaijan.

Activities of CIMMYT economists in the region have identified potential for future productivity growth and assisted policy-makers to draw up viable development plans for the wheat sector. Some special projects (GTZ) grant funds for machinery and equipment, while CIMMYT provides technical advice on the types of machinery and possible sources of supply. Finally, wheat research programs in the region have suffered severe funding cuts, and CIMMYT provides operational support where possible.

CIMMYT's Advanced Wheat Improvement Course: Opening Doors to NARS Senior Scientists

R.L. Villareal

The visiting scientist program is one of CIMMYT's most active training efforts. Since 1966, 1,866 scientists from more than 90 countries all over the world have come to the CIMMYT Wheat Program for short periods, usually two to six weeks (Table 1). CIMMYT has refocused its resources towards receving scientists from countries with less developed national programs, where the need for training is more critical. By supporting these visits each year, CIMMYT encourages personal interaction among wheat researchers, who after completing the course join the ranks of alumni who make up an international research network.

At the Center, visiting scientists have a unique opportunity to exchange ideas among themselves and with our staff, discuss research results, and generally strengthen the interpersonal and professional bonds that hold the international network together. Visitors share their knowledge and experience with CIMMYT staff, trainees, and colleagues from other countries through personal contacts, group discussions, and seminars. Also, they may select wheat, triticale, and barley seed to be shipped to their home countries for use in their crop improvement efforts (it should be stressed that prior to shipping the seed is treated with appropriate fungicides and other chemicals).

Table 1. Origin of CIMMYT's Wheat Program visiting scientists based on regional aggregates, 1966 - 2000.

Origin	Visiting scientists* (no.)
Sub-Saharan Africa	133
West and North Africa	177
East, South, and Southeast Asia	451
Latin America	499
Eastern Europe, Central Asia, and Caucasus	60
High-income countries	546

* Source: CIMMYT Training Database.

Two main categories of professional visitors come to CIMMYT: research directors and policy-makers who come for a short orientation tour, and mid-career, senior scientists who work directly with CIMMYT senior scientists in on-going research programs. These two categories are sometimes confused when visiting scientists are selected or their visits programmed. Of particular concern are policy-makers or active wheat scientists who are sent for 3-6 weeks—too short for a working assignment and too long for an orientation tour. Given the large number of visiting scientists who come to the CIMMYT Wheat Program each year, training resources are stretched to the limit. To maximize the effectiveness of staff time and increase cost effectiveness, the two types of training need to be clarified.

To better distinguish between the two, this paper will not discuss the subject of short-term visits for research directors and policy-makers but will focus instead on the CIMMYT Advanced Wheat Improvement (CAWI) course given in Mexico to mid-career, senior NARS scientists. The course was established in an attempt to further define and more efficiently manage the active visiting scientist program. It should be noted that the CAWI course is an integral part of CIMMYT's Global Project 8, "Building partnerships through human resource development."

Objectives of the CAWI Course

The CAWI course has two main objectives: 1) to impart to senior NARS scientists knowledge on the efficient management of a germplasm improvement program, and 2) to give NARS scientists the opportunity to select new wheat germplasm from the CIMMYT wheat breeding program. There is little question that senior working scientists profit greatly by coming to Mexico and working side by side with CIMMYT scientists. The experience exposes them to the most up-to-date methods and materials available at CIMMYT, gives their work a valuable boost, and provides valuable stimulus to national programs. When courses are properly programmed, a visiting scientist may spend one and a half to two months at CIMMYT and then return home without missing a cycle within the national program.

Profile of CAWI Participants

The major focus of the CAWI course is on senior-level researchers. Criteria for selecting participants include: the candidate must be fully employed, occupy a senior position in the national wheat program (e.g., senior breeder or pathologist, or genetic resources staff), have at least five years of wheat research experience, and a working knowledge of English.

Course Content and Logistics

The CAWI course offers participants: 1) a combination of lectures, laboratory classes, and field work to ensure a good balance of scientific theory and its practical applications; 2) direct and personal relationships with CIMMYT staff, whereby participants learn to appreciate the dignity of field work and the satisfaction and pride that comes from doing this important task; 3) the unique opportunity to come into contact and discuss their circumstances with colleagues from many countries; and 4) the initiation of a long relationship with CIMMYT.

The course curriculum was developed in response to the needs of collaborating countries. This allowed the identification of what was needed in terms of instructors and support staff, teaching materials, laboratories, books, manuals, and inputs, as well as housing, food, transportation, and operational costs. CIMMYT's experienced wheat training staff provided counsel on these matters.

The exchange of germplasm is an important aspect of this program. Visiting scientists send germplasm to CIMMYT, and while at the Center, they can observe the performance of their materials. In return, they have the opportunity to select germplasm from CIMMYT's extensive nurseries for use in their own varietal development programs. The concept of international cooperation—the exchange of information and breeding materials—is a significant component of this course.

The advanced course is scheduled to take place once a year or every other year, depending on financial availability. The six-week course is scheduled to coincide with the wheat selection/ harvest period so that participants can acquire practical experience. Throughout the course, participants work and interact constantly with each other and with CIMMYT staff of all disciplines in both classroom and field, as they conduct research activities. The experience fosters camaraderie between staff and participants, and increases their confidence, knowledge, competence, and appreciation of field activities. Participants also acquire an appreciation for the multidisciplinary approach to wheat improvement.

Course Venue

The CAWI course is held at the experiment stations at El Batan and Toluca, near Mexico City, or in Ciudad Obregon, Sonora. CIMMYT's long wheat training experience, access to a wide array of germplasm, infrastructure, availability of physical, teaching, and financial resources, as well as the involvement of a considerable number of highly skilled, experienced wheat scientists are some of the advantages of conducting the course in Mexico. Participants are exposed to effectively organized wheat crop programs that provide them with models they may develop and adapt to their own situations.

The First Advanced Wheat Improvement Course

The first CAWI course was conducted from September 4 to October 6, 2000 at CIMMYT headquarters in El Batan near Mexico City and at the Toluca experiment station in the State of Mexico with the participation of six senior wheat scientists from five countries, whose names, job titles, and home countries are presented in Table 2. The course ran for five weeks, including four weeks of classroom, laboratory, and field activities and a week for germplasm collection and special, individualized programs. Three participants had PhDs in plant breeding, two Master of Science degrees, and one had a Bachelor of Science in agriculture and the title "Professor." Four of them worked on spring wheat breeding, and the other two on winter/facultative wheat.

Administering a written or practical test was deemed unnecessary considering the status and experience of the participants. We therefore used pre- and post-training questionnaires to evaluate the performance of participants and determine the relevance of the course curriculum to their needs. Participants rated themselves before and after the course in terms of their knowledge and perception of the importance of a range of topics. The list of 44 topics taught during the 2000 course is presented in Table 3.

The overall average pre- and post-course knowledge assessment scores were 2.1 and 3.3, respectively. The post-course knowledge score of 3.3 meant that our six participants felt they possessed the skills taught during the course. On topic assessment, mean scores of 2.7 pre-course and 3.4 post-course indicate that the participants began the course with a good idea of which topics are important and completed the course with a heightened appreciation of the relevance of these topics to their work. None of the participants suggested additional topics to be included in future courses. This means that the topics covered were considered relevant and important to their wheat own research back home. The topics that rated the highest score (4.00) were germplasm bank, genetic resources in breeding, management of a wheat breeding program, and bread wheat breeding.

Table 2. Name, job title, and home country of advanced wheat improvement course participants, 2000.

	Name	Job title	Country
1.	Dr. Md. Abdus Samad	Wheat Principal Scientific Officer	Bangladesh
2.	Mr. Yao Jinbao	Wheat Breeder	China
3.	Prof. Zou Yuchun	Senior Plant Breeder	China
4.	Dr. Minura Yessimbekova	Head Cereal Crops Dept.	Kazakstan
5.	Mr. Dhana Bahadur Gharti	Senior Scientist (Plant Pathology)	Nepal
6.	Dr. Kenan Yalvac	Head Breeding and Genetics Dept.	Turkey

Table 3. Topics covered during the CIMMYT advanced wheat improvement course, 2000.

	Topics
1.	World wheat situation
2.	Concept and philosophy of wheat mega-environments
3.	Adaptation to mega-environments
4.	Germplasm bank
5.	Applying genetic resources to wheat breeding
6.	Managing a wheat breeding program
7.	Handling segregating materials and yield trials
9.	Seed production and multiplication
10.	Concept and application of disease resistance breeding
11.	Applying statistics to wheat research
12.	Hybrid wheat development
13.	Creating a successful wheat breeding program
14.	Quality issues in wheat
15.	Experiment station management
16.	Bread wheat breeding
17.	Durum wheat breeding
18.	Triticale breeding
19.	Barley breeding
20.	Wide crosses in wheat
21.	Applying physiology to wheat breeding
22.	Double haploids
23.	Breeding for nutrient use efficiency and toxicities
24.	Sustainable cropping systems
25.	Wheat "bed planting" technology
26.	Synthetic bread wheats
27.	Managing an international nursery operation
28.	Wheat rust diseases
29.	Fusarium head scab
30.	Barley yellow dwarf virus
31.	Septoria diseases of wheat
32.	Foot rots and nematodes of wheat
33.	Photoperiodism in wheat
34.	Vernalization in wheat
35.	Earliness in wheat
36.	Physiological races of wheat rusts
37.	Global impact of CIMMYT wheat research
38.	Applying biotechnology to wheat improvement
39.	Preparing a research proposal
40.	The International Wheat Information System (IWIS)
41.	Breeding for drought resistance
42.	Plant nutrients
43.	Breaking the yield barriers
44.	Collaborative wheat breeding efforts

Five participants thought the level of instructional materials was about right, while one found them somewhat difficult. All participants felt the curriculum was well planned, highly organized, and very relevant to their current work and responsibilities. The "Reference Manual" was found extremely useful and informative. On the duration of the course, three participants felt that five weeks was about right, while the other three felt that 6-8 weeks would be ideal. They also commented that one week for collecting germplasm was too short; they needed at least two weeks to study the materials, harvest, and process the selected materials for shipment. They all felt that the lecture followed by demonstration/ practical teaching methodology used by most staff was very effective. On language ability, training in class and field, and interpersonal relations, all participants found their trainers competent to very competent. As for the weekly program, participants suggested scheduling at least half a day to interact, discuss, or follow up on topics of special interest with staff and to use the library.

All trainees felt that the wheat improvement technologies learned during the course were very appropriate to home-country conditions. They also believed their abilities as wheat scientists had improved after the course. Their expectations in terms of making international friends/or contacts, collecting new reference materials and publications, having the opportunity to travel, and saving some money were satisfied. As for continued support from CIMMYT, most participants felt that receiving new publications and returning to CIMMYT as visiting scientists after several years would be most useful.

The participants made the following comments:

- Course curriculum was complete and covered very important topics.
- The "lecture followed by practical application" format employed during the course was very effective.
- The Reference Manual very useful, informative, and excellent pre-lecture material.
- Participants appreciated the opportunity to give a presentation or seminar on his/her own research work.
- Participants appreciated having at least half a day per week of free time to seek one-to-one discussions with staff on specific issues and to use the library.

They also made some valuable suggestions and pointed out some positive aspects of the course:

- More brainstorming or discussion sessions on key wheat improvement issues.
- More opportunities to practice special techniques (e.g., use of IWIS and alpha lattice analysis).
- Extending the germplasm collection period to two weeks.
- Excellent schedule of field trips and weekend activities.
- Loving and caring behavior of the organizer.
- Course organization was very good.

Finally, participants felt the advanced course is unique and effective in increasing the expertise of those who attend. Furthermore, they recommended that a greater number of active scientists from developing nations be given the opportunity to visit Mexico and contribute to and profit from CIMMYT's wheat research program.

Program Outlook

The need for good germplasm is obvious, as is the need for highly trained scientists, capable of selecting superior varieties and determining the most adequate and efficient practices that allow farmers to obtain stable, superior yields. Well-trained scientists are essential to the progress of national agricultural research programs in the developing world. CIMMYT will continue to offer the advanced wheat improvement course to help NARS staff achieve their goals. The Center is also committed to assisting national training programs wherever and whenever possible. In conclusion, CIMMYT's wheat training program will respond to and anticipate the training needs of national wheat scientists by providing opportunities tailored to their specific circumstances.

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CIMMYT-Derived Bread Wheat, Durum Wheat, Triticale, and Barley Varieties Released in 1999-2000

SPRING BREAD WHEAT

Name	Abb	Pedigree	Selction History	Synonym	Year	Country
ANNA 2000 T	AN2000	KVZ/BUHO//KAL/BB	CM33027-F-15M-500Y-0M-87B-0Y-2MXI-0MXI	VEERY	2000	Mexico
ARMAGE-DDOM	IAC370	BOW/NAC//VEE/3/BJY/COC	CM92066-J-0Y-0M-0BRA	BABAX, IAC370	1999	Brazil
BARBARA 2000 F	BARBARA 2000	KVZ/BUHO//KAL/BB	CM33027 -F-15M-500Y-0M-87B-0Y-1MXI-0MXI	VEERY	2000	Mexico
BAHAWALPUR 97	BHW97	OREF1 158/FDL//KAL/BB/3/NAC	CM47634-0PAK	METALTAIL	1999	Pakistan
CACHANILLA F2000		PFAU/WEAVER	CMBW90M4-30-0Y		2000	Mexico
CHENAB 99	CHB99	CHUM18/BAU	CM91045-0PAK	CATBIRD	1999	Pakistan
DIANA 2000 F	DN2000	HER/SAP//VEE	CM74849-2M-2Y-3M-2Y-0B-48M-0Y-0MXI	TUI	1997	Mexico
ERA F 2000	ER2000	TUI/MILAN	CMSS92Y00540S-30Y-015M-0Y-0Y-18M-0Y-0MEX		2000	Mexico
FINSI F 2000	FINSI	THB//MAYA/NAC/3/RABE/4/MILAN	CMSS92Y02157T-50Y-015M-010Y-010Y-8M-0Y-1SJ-0Y-0MEX		2000	Mexico
GORRION SNA	GORR	LFN/SDY//PVN	SWM7215-2Y-3Y-0Y-9Y-0Y-0CHL	STAR	1999	Chile
HALCON SNA	HALCON	ND/VG9144//KAL/BB/3/YACO/4/VEE#5	CM85836-38Y-0M-0Y-4M-0Y-0CHL	ATTILA	1999	Chile
HAR1920	HR1920	MON/VEE//SARA	CM88357-49M-0Y-0M-10Y-0M-0ETH		1999	Ethiopia
HAR2192	HR2192	VS73.600/MRL/3/BOW/YR//TRF	CM75113-B-5M-1Y-05M-3Y-2B-0Y-0ETH	MILAN	2000	Ethiopia
HAR2419	HR2192	PEG/PF70354/4/KAL/BB//ALD/3/MRNG	CM58350-A-1Y-3Y-2M-2Y-0M5SJ-010Y-0M-0ETH	BURRION	2000	Ethiopia
HAR2501	HR2501	CHIL/PRL	CM92803-91Y-0M-0SY-5M-0RES-0SY-0ETH		1999	Ethiopia
HAR2504	HR2504	PFAU/SERI//BOW	CM85295-0101TOPY-2M-0Y-0M-1Y-0M-0ETH	PASTOR	2000	Ethiopia
HAR2508	HR2508	BJY/COC//PRL/BOW	CM95439-63Y-0H-0SY-5M-0RES-0SY-0ETH		2000	Ethiopia
HAR2536	HR2536	PRL/VEE6//MYNA/VUL	CM90722-22Y-0M-0Y-5M-0Y-0ETH	PRINIA	1999	Ethiopia
IBTA BARJA	BARJA	HER/SAP//VEE	CM74849-0BOL	TUI	2000	Bolivia
IBTA CHARCAS	ICHA	BUC/FLK//MYNA/VUL	CM91575-0BOL	IRENA	2000	Bolivia
LAURA 2000	LR2000		CM91035-0M-04T-02M-0T-0M		2000	Mexico
LE2265	LE2265	PGO//CHEN/AE.SQUARROSA92240/3/WEAWER			2000	Uruguay
NAHUATL F2000	NAHU	E7408/PAM//HORK/PF73226/3/URES/4/OPATA/5/OPATA/BOW	CMBW89Y00804-0TOPM-9R-0C-2R-3C-0R		2000	Mexico
NINGMAI 10	NMG10	SHANGHAI 7//PRL/VEE	CM95117-F2-0CHN		1999	China
OPALA-INIA	OPALA	OPATA//HAHN/2*PRL	CM94680-4Y-0M-0Y-3M-0C		1999	Chile
PASTOR F 2000	PS2000	PFAU/SERI/BOW	CM85295-0101TOPY-2M-0Y-0M-3Y-0M-0MEX	PASTOR	2000	Mexico
QUELTEHUE SNA	QUEL	HD1220/3*KAL//NAC	CM40454-11M-4Y-2M-3Y-0M-0CHL	NEELKANT	1999	Chile
REBECA F2000	REBECA	PFAU/SERI//BOW	CM85295-0101TOPY-2M-0Y-0M-1Y-0M-0MEX	PASTOR	2000	Mexico
SHIROODI	SHIR	ND/VG9144//KAL/BB/3/YACO/4/VEE#5	CM85836-50Y-0M-0Y-3M-0Y-0IRN	ATTILA	1999	Iran
TOWPE,LBN	TWP,LB	TOW/PEW	CM59443-4AP-1AP-4AP-1AP-0AP-0LBN	TOWPE	1999	Lebanon
VICTORIA 2000 F	VC2000	JUP/EMU//GJO	CM43598-II-8Y-1M-5Y-0M-100R-0R-0MXI	FLYCATCHER	2000	Mexico
WINSOME		HORK/YAMHILL//KAL/BB	CM38212-I-7Y-2M-1Y-3M-2Y-0M-0USA	PFAU	2000	USA

WINTER BREAD WHEAT

GOKSU99	GOKSU	AGRI/NAC	SM6599-2H-1H-3P-0P-5M03WM-0WM		1999	Turkey
CENTINEL 2000	CETI	MLC/4/VPM/MOS95//HILL/3/SPN	OWC852672-6H-0YC-0R-1YC-0YC-0E		2000	Turkey
MASHAD	MASHAD	SPN/MCD//CAMA/NZT	SWM777627-17H-4H-1H-0H		2000	Iran

CIMMYT-Derived Bread Wheat, Durum Wheat, Triticale, and Barley Varieties Released in 1999-2000. cont'd...

DURUM WHEAT

Name	Abb	Pedigree	Selction History	Synonym	Year	Country
ALTAIR				SYRIAM 4		Spain
ATIL		SOOTY_9/RASCON_37	CD91B1938-6M-030Y-030M-4Y-0M		2000	Mexico
CARMINA C-00	CARM	ALTAR 84/FOCHA//MORUS 1	CD92728-040PAP-2Y-040M-1Y-0PAP-0MEX		2000	Mexico
CRISTAL SNA	CRST	RANCO/HUI	CD58230-3Y-1M-1Y-2M-0Y-0CHL		1999	Chile
D.MENDO		SRN 2//YAV/HUI			2001	Spain
DON ANDRES		YAV/TEZ//SRN			2001	Spain
DON MANUEL *(PRELIM)*		FUUT//HORA/JOR/3/RASCON_21/4/PLATA_16	CDSS93B00601T-A-1Y-0M-0Y-0B-1Y-0B	TDA 5	2001	Spain
DON RAFAEL *(PRELIM)*		GREEN_2/FOCHA_1	CDSS93Y137-15Y-0M-0Y-0B-1Y-0B	TDA 6	2001	Spain
GENERAL		VAR SAADA3//CMH82.694/ACO89/3/ACO89			2001	Spain
GUEAGUEA				BUSHEN 6	2001	Spain
HI 8498					1999	India
LUNA SNA	LUNASN	YEL/BAR/3/GR/AFN/CR/5/DOM/CR*2/GS/3/SCO//HORA/6/LAP75/GUIL	CD68057-1Y-6M-1Y-0M-0CHL		1999	Chile
MARIANA 2000-C					2000	Mexico
MENESES		PLATA 1/SNM//PLATA 9			2001	Spain
MONTORO		DUKEM/KITTI//AJAIA			2001	Spain
OPALO SNA	OPALO	MLN69/HUI/SOMO	CD58767-A-7M-1Y-1M-0Y-0CHL		1999	Chile
PERDIZ				DIPPER	2001	Spain
RIO ZUJAR	RZUJ	CHEN/ALTAR	CD57005-5M-3Y-5H-1Y-0M-0EX		1999	Spain
SHW/MALD					2000	Iran
SILVIA 2000-C				ANADE 12	2000	Mexico
SOFIA 2000-C				RASCON 37	2000	Mexico
STORK					1999	Iran
WH 912					1999	India
WH 913					1999	India
YAVAROS 79					1999	Iran
TRITICALE						
AC ULTIMA	ULTIMA	DRAGO/IBEX//CIVET2	SWTY87.246-1B-3Y-2B-5RES-0B-6Y-0PAP-1Y-0B-0CAN		2000	Canada
BRS 203	BRS203	LT1/RHINO	SWT2201-4Y-1M-1Y-4B-3Y-2B-0RES-10FG-3F-2F-0F		2000	Brazil
CERRILLO	CERR	FAHAD4/FARAS1	CTY89.179-5Y-0M-2Y-0M-6Y-0M-2B-0Y-0MEX		1999	Mexico
MARAVILLA	MVLL	DAGRO/IBEX//CIVET2	SWTY87.246-1B-3Y-2B-4RES-0B-1Y-0PAP-3Y-0B-0MEX		1999	Mexico
MILENIO TCL3	MLIO	RHINO_3/BULL-1-1	CTB88.1317-25B-0Y-3M-1Y-0M-1B-0Y-0MEX		1999	Mexico
QUEBRANTAHUESOS-TCL99	QBTH	ZEBRA79/LYNX*X/FAHAD1	CTY90.1406-1M-1Y-0M-4Y-0M-2B-0Y-0MX		1999	Mexico
SIERRA DE ALMARAZ	SIALZ	MERINO/JLO//REH/3/HARE	CTM19808-12M-0Y-0M-0Y-60M-1Y-0B-0EX		1999	Spain
SIERRA DE ARROYO	SIARR	TESMO8/LIRA//BGL/JLO	CIT3049-0Y-5M-3Y-2M-3Y-0B-0EX		1999	Spain
SIERRA DE LA CIERVA	SICV	GRF/ZEBRA31	CTM13889-6EX-4EX-15EX-15EX-0EX		1999	Spain
SIERRA DE LOBOS	SILB	BTA/YOGI	CTM7487-015M-0YZ-0M-0Y-12EX-6EX-0EX		1999	Spain
SIERRA DE VILLUERCAS	SIVL	OCTONV/HARE//BCH/SPY RYE	B6811-270-27Y-3Y-0M-0EX		1999	Spain
SIGLO TCL21	SIGLO	STIL/YAV79//CENT.MAROC54/3/ARDI_1/4/TAPIR/YOGUI_1//2*MUSX	CTM87.1801-2Y-0M-11RES-7M-1Y-0PAP-4Y-0B- 0MEX		1999	Mexico
SUPREMO TCL2000	SP2000	BULL_10/MANATI_1	CTY90.169-25Y-0M-8Y-0M-2B-0Y-0MEX		1999	Mexico
TENTUDIA	TENTUDIA	M2A/MIA	X27947-22M-1Y-0M-0EX	TIGRE	1999	Spain
BARLEY						
BICHY2000	BI2000	ESCOBA/3/MARIOLA/SHYRI//ARUPO*2/JET/4/ALELI	CMB94A.732-J-2M-2Y-1M-12Y-0Y-0MEX		1999	Mexico