Triticale

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Cover photograph: T. Harris

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Significant advances have been made in triticale breeding over the past 20 years at CIMMYT and elsewhere, and the crop increasingly shows promise in difficult production environments.

Introduction

Research on triticale (X. *Triticosecale* Wittmack), the product of a cross between wheat and rye, actually began at CIMMYT a year before the Center was formally established in 1966. The program's original objective was to develop a grain crop to complement or surpass other cereals–a formidable challenge, given the problems triticale initially possessed. Plants were generally tall and late maturing, sensitive to daylength, partially sterile, and tended to set shriveled seed. These problems determined the early agenda for triticale improvement.

In the years since CIMMYT and other scientists first took up that agenda, significant advances have been made. Difficulties with lodging, floral fertility, poor grain quality, and late maturity have been resolved to a great extent, and now over one million hectares of triticales are grown in 32 countries throughout the world (Table 1, page 21). Triticale still retains some undesirable characteristics, including preharvest sprouting and low test weights in less favorable production environments. However, the crop has increasingly revealed its potential under such special growing conditions as semiarid environments, acid soils (for example, Oxisols and Ultisols), and tropical highlands above 1500 m (characterized by volcanic, mostly acidic soils with high phosphorus-fixing capacity).

Such environments as these, where grain production can be a difficult or marginal activity, are receiving increasing attention at CIMMYT. While the triticale program continues to seek means of raising yield and improving wide adaptation, seed quality, and quality for milling and baking, a stronger effort is now being made to breed for stress environments and disease resistance. Underlying each facet of the breeding work is an expanded project to broaden triticale's genetic variability. This project, which is one of the highest priorities of the triticale program, is discussed in greater detail on page 15.

These objectives reflect a confidence in triticale's potential that has not always existed. Although from its first appearance in the 1870s triticale piqued breeders' curiosity as a botanical oddity, it did not readily capture their imaginations as having the potential to become a commercial crop. This transformation was to come later, accomplished through the efforts of many people who believed that triticale's unusual characteristics were worth exploiting. Some of the details of that process, including CIMMYT's achievements in triticale improvement during the past 20 years, are reviewed here, and the program's present and future goals are discussed.

Early Research

In 1875, Wilson reported to the Botanical Society of Edinburgh that he had grown a sterile plant from a wheat x rye cross. Although the first fertile triticale was produced in 1888 by Rimpau, triticale remained relatively insignificant well into the early decades of the twentieth century. At that time, scientists in the Soviet Union and Europe, most notably Müntzing in Sweden, began to explore its commercial potential. Their efforts were frustrated by the hybrid's persistent infertility, its tendency to set shriveled seed, and the impossibility at that time of producing large numbers of fertile new wheat x rye hybrids (referred to as "primary" triticales, as opposed to "secondary" triticales, which are the improved progeny of primaries).

New Techniques for Producing Primary Triticales

The first breakthrough in producing fertile primary triticales came in 1937 with the discovery of colchicine, a poisonous alkaloid derived from the corms or seeds of the autumn crocus (*Colchicum autumnale*). With colchicine treatment, plants could be induced to double their chromosome number and thereby overcome fertility barriers (Figure 1). It became possible to artificially create fertile primary triticales, and the painstaking search for spontaneously occurring fertile triticales, whose appearance in nature is relatively infrequent, was no longer necessary.

The second major contribution to triticale production occurred during the 1940s when embryo culture techniques were developed. Embryos were removed from their abnormal endosperms before abortion and transplanted to a nutrient culture medium. This technique is especially critical in producing hexaploid triticales (42 chromosomes) from durum (*Triticum turgidum* var. *durum*) x rye (*Secale cereale*) crosses. Because of the high degree of cross incompatibility, embryos from such crosses must inevitably undergo embryo culture, and plantlets later receive colchicine

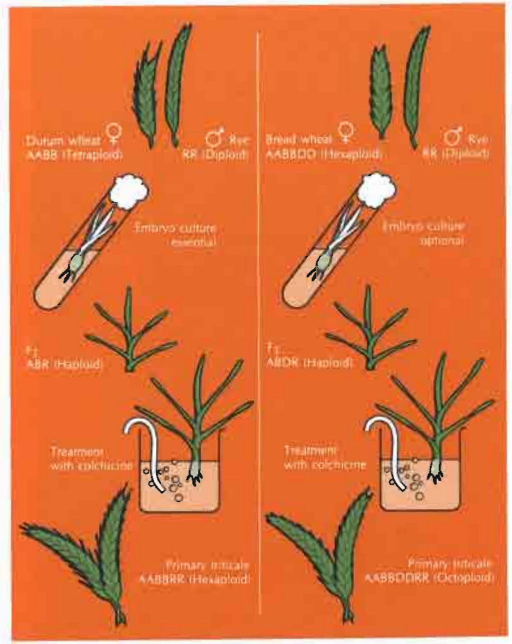


Figure 1. Crossing a durum wheat with rye leads to hexaploid triticale; crossing bread wheat with rye leads to octoploid triticale. The F_1 progeny from both crosses are haploid and, therefore, unable to reproduce sexually. Treatment with colchicine doubles the chromosome number, making the plant self-fertile.

Durum wheat (top left) by rye (top right) crosses produce primary triticales (center), whose improved progeny are referred to as secondary triticales (bottom).

treatment. The F_1 haploid seed of bread wheat (*Triticum aestivum* L.) x rye crosses, on the other hand, can usually be planted directly, without embryo rescue, and then undergo colchicine treatment. In each case, numerous crosses are required to produce viable diploid primary triticales, since initial seed set is generally poor (2-3 haploid seeds per spike).

Often the germination of these intergeneric F_1 triticale hybrids is low, as is the recovery of durum x rye embryo-derived plantlets. Colchicine treatment does not always double the chromosomes and often kills the plantlets. Following treatment, the recovery of doubled seedlings is commonly less than 40%. Between 1972 and 1985, CIMMYT staff made about 2400 crosses for hexaploid (6X) and 1700 crosses for octoploid (8X) primary triticales. Only 700 hexaploid and 400 octoploid triticales were recovered, and less than 30% of the desired wheat and rye combinations were created. These figures illustrate the cost and time involved in producing new triticales.

Advances with Hexaploid Triticales

Triticale research benefited greatly from the refinement of colchicine and embryo rescue techniques, and for the first time primary triticales could be produced in sufficient numbers. In 1954, the University of Manitoba, Canada, assembled a large collection of primary triticales from researchers and institutions throughout the world, and began to make secondary crosses.

This work, and that of Sanchez-Monge in Spain and Kiss in Hungary, confirmed that hexaploid triticales (hybrids of tetraploid durum wheat x diploid rye, 42 chromosomes) possessed breeding qualities superior to octoploids (hexaploid bread wheat x rye, 56 chromosomes). Since 1913, various breeders had worked with hexaploids, but the early hexaploids had poor seed development, and breeders were reluctant to expend further effort on such unpromising materials. However, the Canadian, Hungarian, and Spanish breeders believed that better hexaploid triticales could be produced, and they made significant progress in realizing the potential of hexaploids. In 1969, "Rosner," a hexaploid triticale, was certified for release in Canada; "Cachurulu" was released in Spain, and two other varieties were grown on 15,000 ha in Hungary for animal feed.

Triticale Research at CIMMYT

The basis of CIMMYT's triticale program, like that of its wheat breeding program, existed before CIMMYT's founding in 1966. In 1965, the Rockefeller Foundation awarded a special grant to Dr. N.E. Borlaug and his team in Mexico, in conjunction with the University of Manitoba, to conduct triticale research. It was thought that progress would be more rapid if research were conducted where two crop cycles per year, instead of one, were possible, and where breeders had access to diverse material from bread and durum wheat germplasm development programs, such as those in Mexico.

After CIMMYT was founded, this cooperative research continued under the leadership of Dr. F.J. Zillinsky (additional funding was provided by Canada through the International Development Research Centre and the Canadian International Development Agency). The program made use of sites in three different climatic zones to grow and select populations. In the winter, the triticale nursery was grown at the Northwestern Agricultural Research Center (CIANO), State of Sonora, at 27.5 N latitude, 39 meters elevation. Summer nurseries were grown in the Toluca Valley at 19.2 N latitude and 2640 meters elevation, and in Winnipeg, Manitoba, at 50°N latitude and 230 meters elevation. Thus the number of generations grown per year doubled and the number of environments tripled.

The program began its work with materials that not only possessed such inherent liabilities as sterility and tallness, but lacked the wide adaptation that would permit them to be grown under various conditions around the world. Triticales for developing countries in regions between 30°N and 30°S latitudes required daylength insensitivity such as that possessed by CIMMYT wheats, so achieving this characteristic was one of the program's first objectives. Alternating generations between various stations with differential light regimes and agroclimatic conditions permitted breeders to screen for strains possessing daylength insensitivity (Figure 2). Because endemic diseases differed greatly among the locations, the chances of enhancing the stability of disease resistance were further improved.

"Armadillo" Appears

Soon after the initiation of their program, CIMMYT's triticale breeders benefited from

At CIANO, Dr. F.J. Zillinsky (right), leader of CIMMYT's triticale program from 1966-1982, confers with Dr. G. Varughese, the present program leader.

Figure 2. The key to the success of CIMMYT germplasm is a breeding process called "shuttle breeding" that enables two crop cycles to be grown each year using sites with different agroclimatic characteristics. From November to May, breeding and selection take place in northwestern Mexico; during the rest of the year, materials are selected at sites in south central Mexico. This procedure helps develop lines possessing daylength insensitivity, adaptation to diverse agroclimatic conditions, and resistance to different diseases.

an unforeseen event. "Armadillo," as it came to be called, was a spontaneous outcross of triticale with an unknown Mexican semidwarf bread wheat among the F_3 progeny of the cross X308. (Armadillo was later found to be a substitution of the 2D chromosome from bread wheat for the 2R chromosome of rye. Triticales having D chromosomes substituted for R chromosomes are referred to as "substitute" types, and triticales having all seven R chromosomes are termed "complete" types.)

The good agronomic traits obtained by this chance outcross proved to be highly heritable, and the CIMMYT triticale team took advantage of its good luck; indeed, by 1970, most CIMMYT triticales included Armadillo in their pedigrees. Armadillo materials were distributed to breeders around the world, who used them to endow less promising triticales with high fertility, improved grain test weight and yield, daylength insensitivity, dwarfism, earlier maturity, and good nutritional quality.

International Testing

In 1969, the triticale program initiated international testing to evaluate and disseminate its Armadillo selections and other promising germplasm. The development of widely adapted and stable, high-yielding germplasm clearly requires the cooperation of many scientists around the world. The international triticale testing program involves university researchers and public plant-breeding institutions in exchanges of breeding material and data. Currently, international triticale nurseries from CIMMYT are grown in 71 countries at 115 locations. The increase in the range of environments in which triticales are tested, combined with the expansion of the gene pool, has resulted in a remarkable improvement in adaptation, as manifested in the 14th ITYN trial results from all locations around the world (Figures 3 and 4).

Developing Yield Potential

In their earliest trials in Mexico, triticales failed to yield even half as much as the best locally adapted wheat. By 1969-70, despite the many advantages of the Armadillo genes, triticale yields still were not competitive with Mexico's best commercial dwarf wheat varieties. For example, in the 1969-70 International Triticale Yield Nursery (ITYN)

Nutritional Quality of Triticale

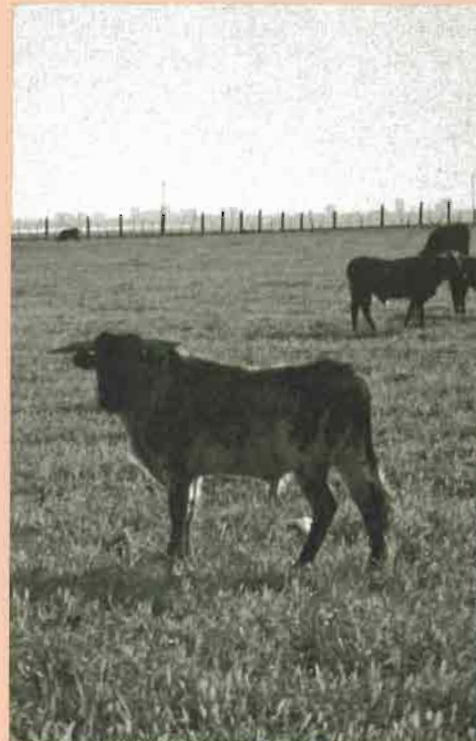
Triticale's nutritional quality is similar to and, in some respects, surpasses that of wheat. In particular, triticale's higher lysine content, better protein digestibility, and mineral balance make it especially suitable as a replacement for or supplement to other cereal grains in human food and animal feed.

As in other cereal grains, the first limiting amino acid in triticale is lysine. However, triticale's lysine content is generally higher than wheat's, and triticale has a better balance of the essential amino acids. The digestibility of protein from triticale grain, when tested in rats, proved to be similar to that of wheat and higher than rye. Furthermore, triticale's phosphorus content is higher than in either of its parent species (4.5 g/kg dry matter, compared to 3.8 g/kg in wheat and 4.1 g/kg in rye), making it a desirable addition to feed for pigs and chickens, whose phosphorus needs are significant.

Numerous feeding studies have reported that triticale is equal to if not better than wheat when used as a component of livestock feed, and the grain has shown promise as a substitute for wheat, maize, sorghum, barley, and rye.

When used as a forage crop, triticale has been found to have higher forage potential and protein content than oats, and higher forage and silage yields than wheat, rye, oats, and barley. Triticale herbage is reported to last longer than rye herbage, and grazing trials with yearling steers recorded average daily weight gains of 0.72 kg for animals grazed on triticale, compared to 0.69 kg for wheat and 0.59 kg for rye.

Some feeding studies in which triticale formed the cereal base in animal diets have reported that the grain did not produce responses consistent with its contribution of nutrients. These results suggest the presence of anti-nutritional factors, presumably carried over from the parent ryes, and imply that caution should be taken in the use of triticale in feed rations. However, many of the discrepancies in results can be attributed to the great genetic variation of the samples tested. Triticale's nutritional advantages, numerous uses, and capacity to grow in more difficult environments combine to make the crop an attractive option for producers throughout the world.



Feeding studies have repeatedly confirmed triticale's feed and forage value.

Armadillo triticale (right) has three characteristics of great value to the breeding program: high fertility, daylength insensitivity, and shorter stature. Two additional advantages of Armadillo, compared to a primary triticale (left), are earlier maturity and more synchronous flowering.

grown at CIANO, the 10 best Armadillo selections yielded an average of 83% of the average wheat yield.

One way CIMMYT breeders sought to enhance triticale yield was to shorten the plant and improve straw strength, thus permitting a heavier application of nitrogen fertilizer without inducing lodging. Early attempts to shorten triticale by incorporating dwarfing genes using UM940, a short, sturdy Canadian line, and dwarf triticales from Hungary, were frustrated by the inability to maintain fertility among the dwarf selections. Another strategy, which involved crossing Armadillo strains with stiff-strawed triticales, resulted in only moderate increases in lodging resistance. A third strategy was to make crosses with a dwarf rye called "Snoopy," which initially brought poor agronomic characters along with it. Although progeny of such dwarf ryes as Snoopy eventually figured into the pedigrees of dwarf triticales, this did not occur until after the success of CIMMYT's next approach to shortening triticale.

In that approach, dwarf hexaploids were first derived from crosses of hexaploid triticale x semidwarf bread wheat and octoploid triticale (based on dwarf high-yielding Mexican bread wheats) x hexaploid triticale. The bread wheat variety "INIA 66" had previously been crossed to two different spring ryes, and two important octoploid triticale lines called "Maya 1" and "Maya 2" were selected from these crosses. These two lines played a major role in reducing the height of triticale as well as in increasing yield, adaptation, and test weight. For example, more than 15 triticale varieties around the world are released from the cross of Maya 2 times Armadillo. The line "Mapache" or "Cananea" is probably the best of this series. By 1975, the most promising triticales had good lodging resistance and the average height of the crop had been markedly reduced. Yield tests demonstrated that triticale could tolerate higher nitrogen inputs without lodging.

The Maya 2 x Armadillo (M_2A) strains, with their additional dwarfing genes, first appeared in replicated trials in 1972-73.

Whereas the yield of the top wheat check held steady at 8000-9000 kg/ha, the best triticale strains had increased their productivity by about 15% to 8000 kg/ha, and the top triticale yielded 8352 kg/ha. The yield gap between the best wheats and triticales in Mexico had been closed for the first time. Figure 3 demonstrates the continued increase in triticale yield as compared to that of the bread wheat varieties included in the ITYN. By 1984-85, results from the 16th ITYN showed that some triticales were comparable to wheats in all locations, and clearly superior under certain stress conditions.

Breeding for Wide Adaptation

Accompanying the triticale program's attempts to increase yield were its efforts to improve broad adaptation, and so obtain triticales that would perform well in varied agroclimatic conditions. Though triticale's genomic constitution theoretically provides a built-in potential for adaptation to a wider range of conditions than those to which wheat is adapted, lack of genetic variability among early triticales, including Armadillo lines, gave these triticales a very narrow range of adaptation compared with

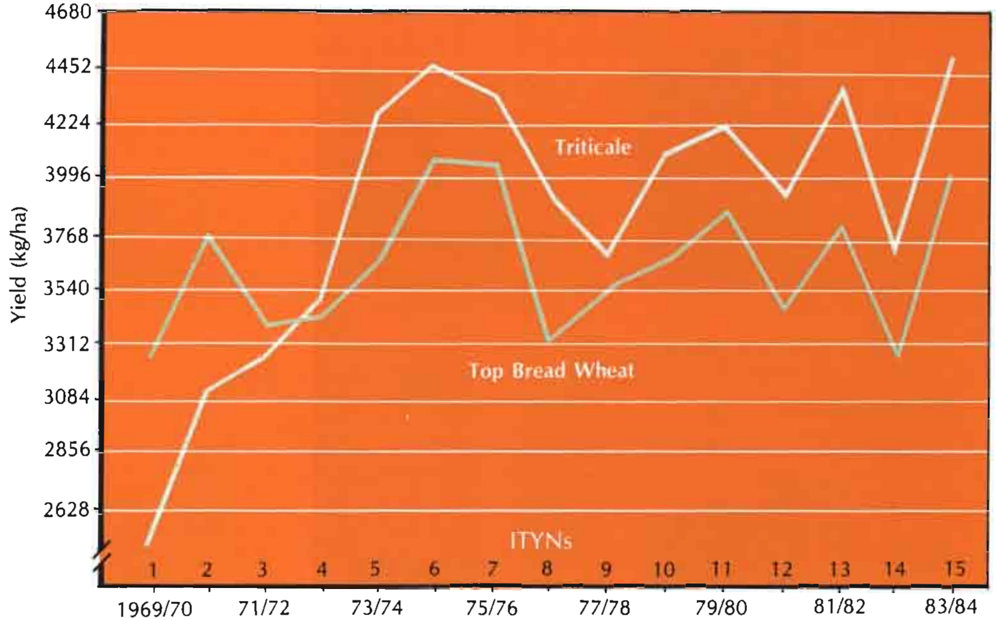


Figure 3. Average yield of the top five triticale lines compared to the top bread wheat in the International Triticale Yield Nurseries (ITYNs), average of all locations, 1969-70 to 1983-84.

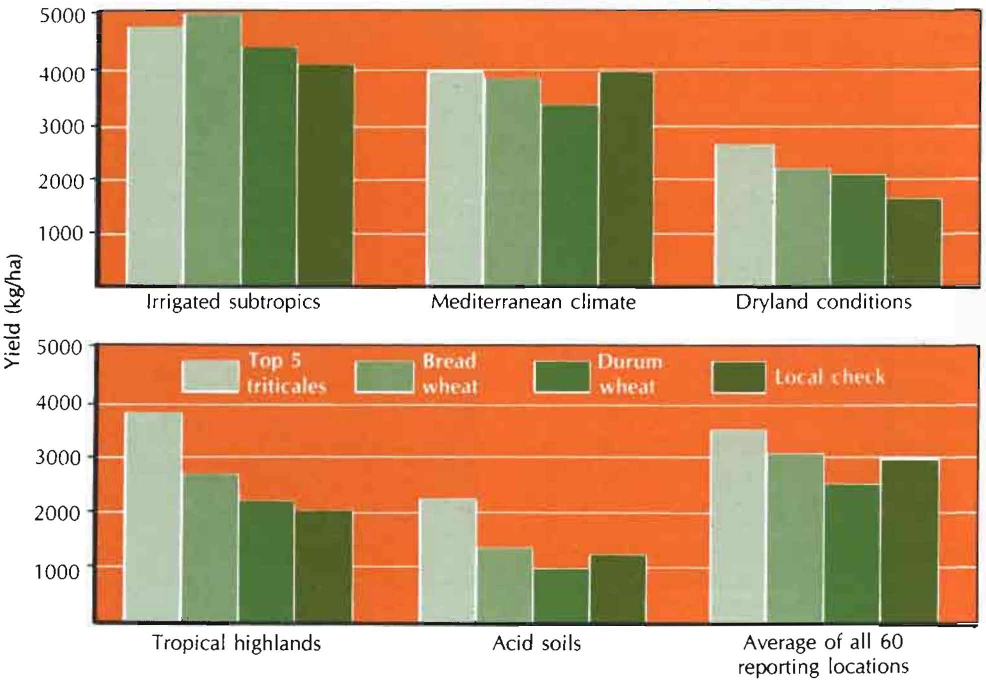


Figure 4. Relative yield performance of triticales under differing agroclimatic conditions compared to the average of all 60 reporting locations and the long-term check varieties. (Based on 14th ITYN data, 1982-83).

semidwarf wheats. With the expansion of the germplasm base and the use of Mexican wheats as source material, triticales increasingly demonstrate wide adaptability and stable, high yield potential.

In Figure 4, results of the 14th ITYN (1982-83) are divided into groups representing different climates and/or specific conditions. In Mediterranean climates where moisture is plentiful, and in irrigated subtropical conditions, triticales had high yields but were not superior to the bread wheat variety Genaro 81. The average of the top five triticales shows a distinct advantage over the bread wheat and local checks in acid soil areas and in the highland tropics. There appears to be an advantage under low rainfall conditions as well, but the differences are not as great. However, caution should be used in interpreting these results, because both bread wheat and durum wheat tend to perform poorly in triticale nurseries.

Triticale's resistance to such diseases as rusts, bunts, and smuts has been another advantage, especially at higher elevations. Its greater resistance to *Septoria tritici* is an asset in areas where this disease lowers yields (for example, in Brazil, Argentina, Ethiopia, and the Mediterranean region).

Furthermore, in marginal environments, complete triticales—those with all seven rye chromosomes—generally perform better than substitute triticales (Figure 5). This observation led CIMMYT's triticale program to shift its emphasis to complete triticales, which presently receive more attention than the substitute types.

Acid soil/tropical highland environments— Tropical highland regions require triticales with resistance to preharvest sprouting and numerous diseases, and which possess improved test weights. Rye has an inherently high tolerance of acid soils, and is probably the source of triticale's generally superior performance in acid soil conditions. In 1983, for example, 10 of CIMMYT's best triticales were compared with the 10 CIMMYT bread wheat lines most tolerant of acid soils, and the least productive triticale yielded more than the best bread wheat. In acid soils and

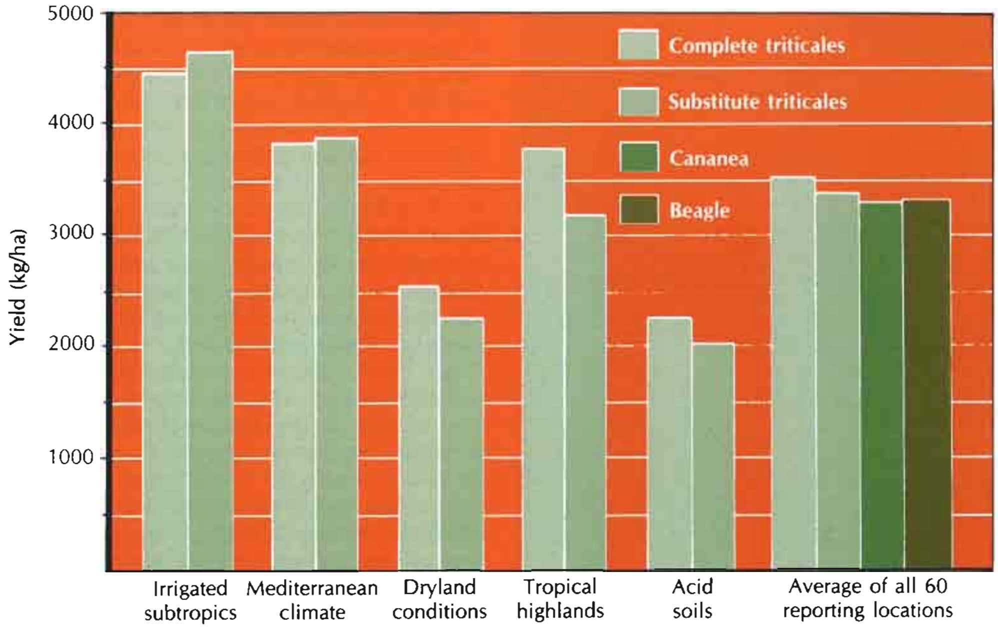
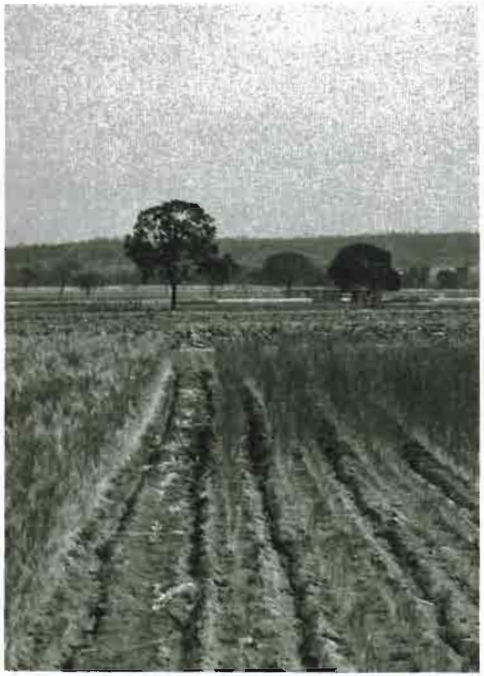


Figure 5. Relative yield performance of the top five complete and substitute type triticales under differing agroclimatic conditions compared to the average of all 60 reporting locations and the check varieties, Cananea and Beagle. (Based on 14th ITYN data, 1982-83.)



In Brazil, the performance of triticale (background) and wheat (foreground) is compared on acid soils (right) and limed soils (left); triticale's advantage over wheat in acid soils is evident.

upland areas, triticale has great promise, and is being adopted by farmers in Michoacan State in Mexico (i.e., the variety Eronga 83) and Rio Grande do Sul in Brazil (such recently released varieties as BR-l, Batovi, Araucaria, Ocepar 1, Ocepar 2).

The breeding strategy for developing materials suited to tropical highlands and acid soils begins with the selection of parents having adaptation to acid soils, and low alpha-amylase activity or sprouting tolerance. Those parental lines, such as "Hare 212," "Stier," and "Tatu" (all found to have low alpha-amylase activity), are then used in crosses. These generations are alternated between Toluca and CIANO, and are also evaluated for one or more generations in acid soils to eliminate unadapted materials. Before being sent for international testing, the most advanced generation material is selected again in Brazil and retested under acid soil conditions in Mexico.

Dryland environments—One primary concern in developing germplasm for moisture-stress regions is ensuring that materials maintain acceptable test weights and yields under drought conditions. Many advanced lines, such as "Rhino" and "Carman/Yogui," presently show excellent test weight and yield potential under drought stress in Mexico. The challenge now is to continue improving these traits while broadening genetic diversity among the drought-tolerant lines.

Varieties and lines with proven potential for tolerance to drought stress are intercrossed to further enhance stress tolerance. The resultant segregating populations undergo selection in stress environments for at least three generations. At every stage, nonadapted populations are eliminated based on their yield and test weight. Surviving populations are then planted under optimal conditions to identify plants that have more genetic yield potential.

A shifting emphasis—Triticale's performance in difficult production environments has prompted the program to shift its emphasis gradually from developing triticales for highly productive, wheat-producing areas, to improving triticales for stress environments where the crop complements wheat production. The triticale program nevertheless commits some of its resources to breeding for optimum crop production environments where an alternative to bread or durum wheat might be needed.

Disease Resistance

Initially, diseases did not appear to limit triticale yields greatly, probably because the amount of triticale being grown was not sufficient to cause serious outbreaks of pathogens. As the area planted to triticale expands, this situation is changing. Since 1971, CIMMYT has monitored the major diseases affecting triticale in Mexico and around the world.

Leaf rust (*Puccinia recondita*) appears to be the most common and variable disease of triticale in Mexico and throughout the world. New races arise periodically and cause infection on some triticale varieties and lines.

Stem rust (*Puccinia graminis*) on triticale was not a problem until recently, when the pathogen mutated sufficiently in Australia to attack triticale. Australian scientists have made significant progress in overcoming this problem by identifying several additional resistance genes, which are now being exploited in various breeding programs, including CIMMYT's.

Stripe rust (*Puccinia striiformis*) was severe on some of the program's first triticale lines, but high levels of resistance have since been incorporated. However, in the East African highlands a situation similar to that of stem rust in Australia seems to be developing for stripe rust. CIMMYT relies heavily on its cooperators to provide information and evaluate germplasm for resistance to diseases, such as stripe rust, for which virulences on triticale do not exist in Mexico.

By creating an artificial epidemic each breeding cycle, using rust races found in Mexico, breeders can produce a continual flow of rust-resistant germplasm in an effort to keep ahead of evolving pathogens. Lines and varieties reported by cooperators as having resistance to pathogens and races not present in Mexico are included in the crossing program to develop germplasm that is potentially resistant to those races as well.

The importance of stem rust (shown here) and other diseases affecting triticale is increasing as the amount of land planted to the crop expands.

Considerable progress has been achieved in triticale seed quality. The wrinkled coat, deep crease, and lusterless quality of earlier triticale grain (right) discouraged its acceptance, but a number of improved lines with plump, high test weight seed (left) have since been identified.

Ergot (*Claviceps purpurea*), a serious disease of the earlier, sterile triticales, is no longer a problem since floret fertility has been improved. Infection levels are similar to those observed in bread wheat. Karnal bunt (*Tilletia indica*), a minor seed-borne disease, affects bread wheats in Mexico, but triticale shows resistance to this and other bunts and smuts. However, triticales still lack adequate resistance to certain important diseases, including scab and snow mold (caused by *Fusarium* species), helminthosporium leaf blotch (*Helminthosporium sativum*), bacterial stripe (*Xanthomonas translucens*), and some root-rots and seedling blights. Breeding for resistance to these diseases, particularly scab and leaf blotch, is an integral part of the CIMMYT triticale program. New sources of disease resistance are being incorporated through interspecific crosses with bread wheat and by the production of new primary triticales. For example, scab-resistant bread wheats from China, including "Shanghai," "Suzhoe," and "Wuhan" lines, are being crossed to triticales, and are also used for making new primary octoploid triticales.

Seed Type and Test Weight

One of the most important unresolved problems in triticale breeding is abnormal endosperm formation. Instead of the smooth, plump seed typical of wheat, ripe triticale seed often has a wrinkled coat, a deep crease, and lacks luster. Malformed seed provides a poor environment for the embryo, and leads to a poor germination rate. As a result, triticale grain is unattractive to many farmers and consumers.

Shriveled seed is reflected in low test weight (weight per unit volume). The best bread wheats have test weights above 80 kg/hl, but early triticale test weights ranged from 58 to 72 kg/hl. Armadillo strains contributed to improving test weight, and selections from the cross INIA 66/Armadillo (X1648), called "Camel," were used extensively by the breeding program. Camel, along with "Panda," a cross derivative of Camel, became the main source for improved test weight in CIMMYT's triticale germplasm. Progress was slow but steady, and at present, test weights above 78 kg/hl are more common under favorable production conditions than in the past (Figure 6). The lines "Yogui," "Zebra," "Rhino," "Dingo," and such derivatives of these lines as Carman/Yogui are good examples of triticales with plump, high test weight seed.

Although test weights tend to decrease under stress conditions, some promising triticale lines (e.g., "Rhino" and "Buffalo") have acceptable test weights under acid soil conditions in the tropical highlands and under drought stress. These lines also maintain superior test weights in optimal production environments. The application of strong selection pressure for improved test weights continues, particularly in triticales grown under stress conditions.

Sprouting Resistance

Triticale seed often contains high levels of alpha-amylase, which is correlated with preharvest sprouting in the spike. With increased sprouting, alpha-amylase activity increases; when sprouting is low, alpha-amylase activity is also low. Preharvest sprouting, along with the crop's incapacity to maintain good, smooth seed after exposure to rain, reduces seed production and lowers the grain's milling and baking quality. This problem is especially persistent in the tropical highlands, where ripening may occur during periods of high rainfall.

CIMMYT scientists have taken two approaches to breeding for sprouting resistance and good seed type. First, triticale strains and segregating populations are planted in Toluca during January so that ripening coincides with maximum rainfall during June and July. This procedure facilitates natural selection as well as screening for sprouting tolerance and the capacity to produce smooth seed. It will become a routine part of the breeding program used to develop materials for highlands and acid soils. In the second approach, laboratory tests are performed to determine the level of alpha-amylase activity. These data are used to eliminate those lines with higher alpha-amylase activity and thus unacceptably low sprouting tolerance. Currently, such lines as "Otter," "Anoas," and Llama/F3Spy//Bgl show low alpha-amylase activity.

Broadening the Germplasm Base

CIMMYT's triticale germplasm pool contains many genes for each of the breeding objectives described previously: stable high yield, wide adaptation, disease resistance, good seed type, and low alpha-amylase

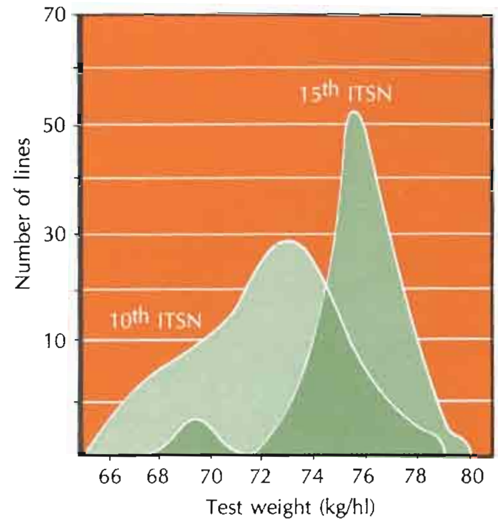


Figure 6. Progress in the improvement of test weights of triticale advanced lines at CIANO experiment station in the tenth (1978-79) and fifteenth (1983-84) International Triticale Screening Nurseries (ITSNs).

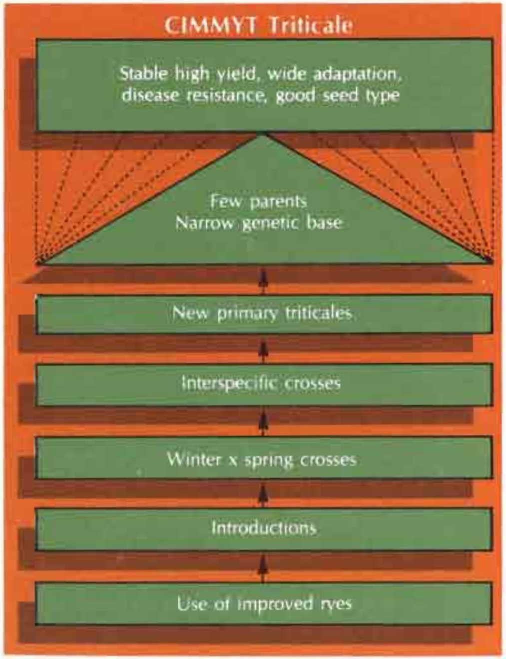


Figure 7. The genetic variability of CIMMYT triticales is being improved using new primary triticales, interspecific crosses, crosses between spring and winter triticales, germplasm from other breeding programs, and improved spring rye germplasm.

activity. However, these desirable genes have come from relatively few sources, and the overall genetic variability for any given trait is somewhat limited. For this reason, the program's highest priority is to increase the genetic variability in its germplasm (Figure 7).

Since triticale has not undergone natural selection, it is both necessary and advantageous to create populations as genetically diverse as possible. Because only a few progenitors possessed traits that contributed to the solution of basic problems limiting triticale production, they were used extensively and tended to restrict triticale's genetic background. For example, as of 1984, approximately 70% of CIMMYT's named breeding lines contained Armadillo in their pedigrees.

The primary source for enhancing triticale's genetic diversity is the development of new primary triticales. In 1984, the CIMMYT program initiated a special project to intensify and improve the production and maintenance of primary triticales. The object of this work is the creation of primaries from parents possessing special characteristics for adaptation to specific conditions, and/or resistance to diseases. New methods of producing primaries are being found by refining such methods as colchicine treatment, and attempting to grow individual embryo cells by tissue culture to generate larger numbers of haploid plantlets per cross.

At the same time, CIMMYT is collecting spring rye germplasm from around the world to broaden the impact from this parent of triticale, which received little attention from breeders in the past. A small spring rye improvement program has been initiated to support triticale breeding efforts.

Several approaches have been undertaken to increase genetic variation in CIMMYT's secondary breeding materials. Thousands of crosses have been made between adapted triticales of different pedigrees. Second, many interspecific hybrids of triticales and bread wheats were produced. Finally, CIMMYT's triticales, all of them spring types, are being crossed with winter triticales. Cooperative research and the exchange of germplasm with winter triticale breeders in Poland, Canada, the United States, Sweden, France,

(Cont'd p. 18)

Triticale Food Products

Because triticale resembles wheat more than rye in grain size, shape, and chemical composition, its food quality characteristics are most often compared to those of wheat. CIMMYT's triticale program has concentrated on developing the crop for human food; research on food products made from triticale and on the industrial quality of the grain is conducted in the Center's grain quality laboratory.

When the quality laboratories first began evaluating triticale grain, it became apparent that triticale flour differs from wheat flour in its bread-making characteristics. Triticales are suitable for products for which soft wheat is used, including cookies, cakes, waffles, noodles, and flour tortillas. At present, many triticale lines possess weak gluten and consequently are unsuitable for producing leavened bread, unless the triticale flour is blended in a proportion not higher than 30% with a good bread-making wheat flour.

Additionally, triticale can be used to make whole-meal breads similar to those consumed in many rural areas of the developing world.

Just as bread wheats vary in their genetic potential for quality, genetic differences for quality characteristics are found in triticale. Some triticale lines are better than others for the preparation of certain products. And as new lines have been developed, the milling and baking characteristics of CIMMYT triticales have changed. Triticales produced in the early 1970s had rather poor milling and baking properties because of their characteristic shriveled grain, deficient gluten quantity and quality, and their high levels of alpha-amylase activity. Improvement of grain plumpness, which has always been a priority for the triticale breeders at CIMMYT, has resulted in the development of many new triticales with better grain type, which have flour-milling properties similar to those of bread wheats.

In CIMMYT's grain quality laboratory, milling and baking properties of triticale grain are evaluated.

Triticale in Poland

In Poland, where rye is used extensively in animal feed and for making bread, winter rye is planted on approximately five million hectares of sandy, acid soils. But rye grain contains antinutritive elements and cannot be used as the major proportion in feed grain mixes. The bread industry cannot use rye blended in high proportions with wheat without reducing quality. Triticale can be used as a component of feed rations and also makes a better blend with wheat for making bread. These characteristics, combined with triticale's adaptation to sandy, acid soils, make triticale an attractive alternative to rye in Poland.

In Szelejewo, Poland, Dr. T. Wolski (left), Scientific Director, Poznan Plant Breeders, reviews field trials with Dr. G. Varughese. The Polish variety "Lasko," released in 1982, is the most widely grown triticale in the world today.

In the mid-1960s, the Poznan Plant Breeders, headed by Dr. T. Wolski, started an intensive triticale breeding program. Their efforts resulted in the registration of the first Polish winter triticale variety, "Lasko," in 1982, and the subsequent release of many other varieties (see Appendix 1 and 2, released triticale varieties). The Plant Breeding and Acclimatization Institute (IHAR) is also actively involved in triticale research. Poland now grows about 250,000 ha of triticale, and Polish breeders project that more than one million hectares will be planted to the crop by 1990. Polish triticales are currently grown in most European countries and other parts of the world where winter plant materials are grown.

Great Britain, Germany, Hungary, and other countries are providing new sources of genetic diversity. Winter x spring triticale crosses make it possible to incorporate the germplasm of improved winter ryes.

Global Status and Future of Triticale

The development of triticale into a commercial crop is a major achievement in plant science, especially considering the relatively short time devoted to crop improvement (Appendix 3). This accomplishment has been brought about by the concentrated application of research and the cooperation of plant scientists throughout the world. The problem of poor yields has been overcome. Triticale yields now approximate those of wheat and rye obtained in areas where these crops are traditionally grown, and surpass wheat yields in many marginal crop production areas. Refinements of basic techniques and new developments in biotechnology offer additional opportunities to further exploit the progenitor species in improving triticales.

More than one million hectares of land throughout the world are now planted to triticale (Figure 8). It is expected that this area will grow significantly in the next decade as awareness of the crop's usefulness increases and markets expand.

Future gains in food production depend greatly on farmers' ability to grow crops in marginal and/or stress environments. Triticale's excellent performance in such areas offers the possibility of raising the productivity of resources committed to food production in locations where such increases may be vital. The crop that was once a botanical oddity is now a commercial reality, and may become an ever more important factor in improving rural welfare in the world's more difficult production environments.

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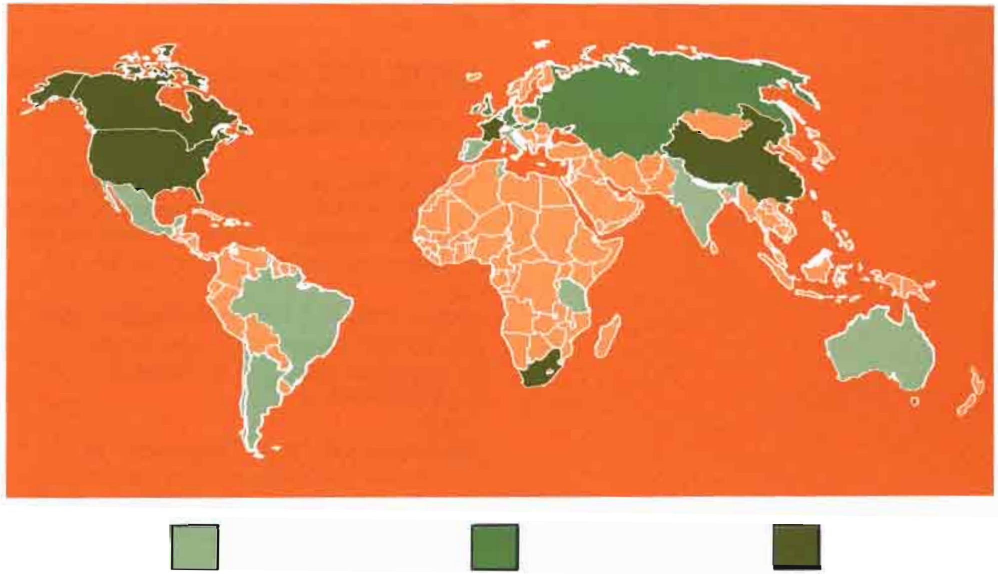

Figure 8. Winter, spring, or both winter and spring triticales are grown in parts of the areas shown above on a total of more than 1,000,000 hectares. (See Table 1 for estimates of triticale area in each country.)

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Table 1. World distribution of triticale, 1986

Country*	Growth habit	Area (ha)
Argentina[1]	S	10,000
Australia[1]	S	160,000
Austria[3]	W	1,000
Belgium[1]	W	5,000
Brazil[1]	S	5,000
Bulgaria[1]	W	10,000
Canada[2]	S+W	6,500
Chile	S	5,000
China[1]	S+W	25,000
Fed. Rep. Germany[3]	W	30,000
France[3]	S+W	300,000
Hungary[1]	W	5,000
India[2]	S	500

S = Spring type
W = Winter type

1 Estimate
2 CIMMYT survey
3 Suijs, L.W. 1986. Le triticale aux Pays-Bas, Allemagne Fédérale, Royaume Uni et le Pays de Gallesc. *In* Triticale: Internationaal Colloquium. Gent, Belgium, Industriële Hogeschool van het Rijk C.T.L.
* In addition to the countries listed in this table, the following countries have released varieties for cultivation: Greece, Kenya, Madagascar, New Zealand, and Pakistan.

Table 1. (Cont'd)

Country*	Growth habit	Area (ha)
Italy[1]	S	15,000
Luxemburg[1]	W	400
Mexico[1]	S	8,000
Netherlands[2]	W	1,000
Poland[1]	W	250,000
Portugal[2]	S	7,000
South Africa[1]	S+W	15,000
Spain[1]	S	30,000
Switzerland[2]	W	5,000
Tanzania[2]	S	400
Tunisia[2]	S	5,000
UK[3]	W	16,000
USA[1]	S+W	60,000
USSR[1]	W	250,000
Total		1,225,800

Appendix 1

Released Spring Triticale Varieties[1]

Name	Abbreviation	KT	Pedigree	Cross No. & Selection	Year	Country
ALAMOS 83	ALM	S	CHIVA"S"	X-24551-8Y-3M-1Y-0M	1983	Mexico
ARABIAN	ABN	S	M2A	X-2802-38N-5M-6N-6M-0Y	1981	Portugal
ARMADILLO	ARM	S	TCL DUR "GHIZA"/TCL DUR "CRLT"/3/TCL PERS/ TCLDUR//TCL DIC/TCL PERS OUTCROSSED TO BW	X-308	1979	Portugal
ASCRET	ASCRET	S	M2A	X-2802	1982	Spain
BACUM	BCM	S	M2A	X-2832-24N-3M-7N-4M-0Y	1981	Portugal
BADIEL	BADIEL				1981	Spain
BEAGLE	BGL	C	UM"S"/TCL BULK	X-1530-A-12M-5N-1M-0Y	1981	Portugal
BEAGLE 82	BEAGLE 82	C	BGL"S"	X-1530	1982	USA
BORBA-1	BORBA-1	C	BOK	X-15673-A-1Y-2Y-1M-0Y	1984	Portugal
BR-1	BR-1	S	PANDA"S" = PFT 766	X-8386-D-2Y-0M-101Y-101B-107Y-0Y	1984	Brazil
CABORCA 79	BURA	S	M2A/IRA	X-8417-A-1Y-7M-3Y-0Y	1979	Mexico
CACHURULU					1969	Spain
CALBUCO-INIA			DRIRA//INIA/ARM/3/M2A	TT.210-1T-T-9T	1984	Chile
CANANEA 79	CAN	S	M2A = MAPACHE	X-2802-F-12M-1N-1M-0Y	1979	Mexico
CARMAN	CARMAN	C	BGL"S"	X-1530-A-12M-5N-1M-0Y	1980	Canada
CEP-15 BATOVI	CEP-15	S	PANDA"S" = TCEP 77138	X-8386-D-2Y-0M-110Y-103B-109Y-1Y-1M-100Y-0Y	1984	Brazil
COORONG	CRG	S	IA	X-1648-5N-2M-0Y-2B-0Y	1980	Australia
CURRENCY	CNY	C	M1A/BGL"S"	X-15552-33H-2Y-2Y-1M-0Y	1983	Australia

1 For additional information, see Abdalla, O.S., G. Varughese, E.E. Saari, and H. Braun. 1986. Spring Triticale: Names; Pareniage; Origins. CIMMYT, Mexico, D.F.

Appendix 1 (Cont'd)

Name	Abbreviation	KT	Pedigree	Cross No. & Selection	Year	Country
DUA	DUA	S	M2A	X-2802	1980	Australia
ERONGA 83	ERONGA	C	JLO 159	X-21295	1983	Mexico
FASCAL	FASCAL	?	?	?	1986	Spain
FLORIDA 201			BGL/M2A	X-15671-FP7	1985	USA
GROWQUICK					1977	Australia
IAPAR 13 ARAUCARIA	IAPAR 13	S	PANDA"S"/RM = TPOL 8432	X-36517-613-H-0Y	1984	Brazil
JUAN	JUAN	C	JLO 168	X-21295	1984	USA
JUANILLO 86	JLO 86	C	DRIRA//KISS/ARM"S"	X-21295	1985	Tunisia
JUANILLO 97	JLO 97	C	DRIRA//KISS/ARM"S"	X-21295	1985	Tunisia
KARL	KARL	S	M2A = ABN"S"	X-2802-38N-5M-6N-6M-1Y-1M-0Y	?	USA
KRAMER	KRAMER	S	M2A = MPE	X-2802-F-12N-1M-1N-1M-0Y	?	USA
LONQUIMAY-INIA		S	M2A*2//TJ/IRA	X-39348-1Y-2t-1t	1984	Chile
MANIGERO	MAN	S	M2A	X-2802	1979	Spain
MAPACHE	MPE	S	M2A	X-2802-F-12N-1M-1N-1M-0Y	1981	Portugal
MARVAL	MARVAL	?	GQ/4/IMPERIAL AMBER/M2A//PITIC62/3/BGL"S"	X-27807	1986	USA
MEXITOL 1	MEXITOL 1	?	Selection from an F_2 population of winter TCL sent to Bulgaria	?	1978	Bulgaria
MIZAR	MZR	S	M2A	X-2802	1979	Italy
MONSANTO	MONSANTO	S	M2A	X-2802-70N-3M-1N-2M-0Y	1983	Portugal
MORRISON	MORRISON	S	TJ/IRA	X-13896-D-100Y-102B-100Y-100-17M-0Y	1985	USA
NIAB-T183	NIAB-T183	S	NIAB77/NIAB 103/M2A	?	1982	Pakistan
NINGADHU	NGD	C	DRIRA SEL	X-7110	1980	Australia

Appendix 1 (Cont'd)

Name	Abbreviation	KT	Pedigree	Cross No. & Selection	Year	Country
OAC DECADE	—	S	M2A//27-4/320	?	?	Canada
OAC TRIWELL	—	C	BGL"S"	X-1530	1980	Canada
OCEPAR-1	OCEPAR-1	C	DELFIN"S"	X-15490	1984	Brazil
OCEPAR-2	OCEPAR-2	C	TJ/BGL =ITOC 8432	X-16134-35Y-1Y-1M-1Y-1B-0Y	1984	Brazil
ROBOLITO	ROBOLITO	S		?	1984	France
ROSNER	ROSNER	C		?	1969	Canada
SALVO	SALVO	C	M2A-274/320*7680	?	?	Poland
SAMSON	SAM 145	C	RAM	X-12257-2N-0M	1984	Australia
SATU	SATU	S	M2A	X-2802	1979	Australia
SISKIYOU	SISKIYOU	C	?	UC 8825	1977	USA
T-50	T-50	S	?	?	1979	Kenya
T-65	T-65	S	?	?	1979	Kenya
TL 419	TL 419	S	?	?	1982	India
TOORT	TOORT	S	KLA/CIN	?	1984	Australia
TOWAN	TOWAN	S	IA	?	1981	Australia
TRITICALE	TRITICALE	S	M2A	X-2802-38N-3M-3N-0N	1983	Tunisia
TRITICOR	TRITICOR	S	M2A	X-2802	1984	France
TRITIVAT	TRITIVAT	?	?	?	1986	Spain
TYALLA	TLA	S	M2A	X-2802	1979	Australia
USGEN 10	USGEN 10	S	FW121/PROL//CIN/YO"R"	X-23963-100Y-4M-0Y	1986	S. Africa
USGEN 14	USGEN 14	S	M2A/M1A	X-27947-22M-1Y-0M	1986	S. Africa
USGEN 18	USGEN 18	C	JLO 100	X-21295	1986	S. Africa
VENUS	VENUS	C	BGL"S"	X-1530-A-12M-5N-1M-1Y-0M	1981	Australia
WELSH	WELSH	S	UM2038	X-1648	1978	Canada
YOREME 75	YE	S	M2A	X-2802-38N-3M-7N-5M-0Y	1975	Mexico

Appendix 2

Released Winter Triticale Varieties (Partial Listing)

Country	Variety
Austria	Lasko
Belgium	Clercal, Lasko, Salvo
Bulgaria	Vihren
Canada	OAC Decade, Wintri
Fed. Rep. Germany	Bokolo, Dagro, Local, Lasko, Salvo, Clercal
France	Clercal, Lasko, Salvo
Hungary	Bokolo
Luxemburg	Lasko
Netherlands	Lasko, Salvo
Poland	Bolero, Dagro, Grado, Lasko
Switzerland	Lasko
United Kingdom	Dagro, Lasko, Newton, Rosko, Salvo, Torrs, Warren
USA	Wintri, Council, Terreland 20, Trical, Flora

Appendix 3

Important Events in the Development of Triticale		
1875	Scotland	A.S. Wilson reports first known wheat x rye cross, resulting in sterile plant.
1888	Germany	First fertile wheat x rye hybrid achieved by W. Rimpau.
1918	U.S.S.R.	Thousands of wheat x rye hybrids appear at Saratov research station. The F_1 plants produce seeds from which true-breeding, fairly fertile, phenotypically intermediate hybrids are derived.
1935	Germany	Name "triticale"—from *Triticum* (wheat) and *Secale* (rye)–appears in scientific literature.
	Sweden	A. Müntzing begins intensive work on triticale.
1937	France	P. Givaudon develops colchicine technique for doubling chromosomes of sterile hybrids, making the production of large numbers of fertile triticales possible.
1940s		The embryo culture technique for rescuing hybrid embryos from seeds with malformed endosperm is developed.
1954	Canada	University of Manitoba, Canada, inaugurates the first North American effort to develop triticale as a commercial crop. L.H. Shebeski, B.C. Jenkins, L. Evans, and others assemble a world collection of primary triticales.

Appendix 3 (Cont'd)

Important Events in the Development of Triticale

1964	Mexico	The International Wheat Improvement Project of the Rockefeller Foundation makes an informal agreement with the University of Manitoba to expand work on triticale.
1965	Canada	The Rockefeller Foundation makes a three-year grant to the University of Manitoba for research on triticale in collaboration with the Foundation's International Wheat Improvement Project in Mexico.
1966	Mexico	CIMMYT is founded; cooperative triticale research with the University of Manitoba continues.
1968	Mexico	The "Armadillo" strain, with almost complete fertility, one dwarf gene, and superior plant type, appears spontaneously in CIMMYT plots at CIANO. This strain becomes an important progenitor for triticales throughout the world.
	Hungary	Two secondary hexaploids developed by Kiss in 1965 are certified for commercial production and release.
	Spain	The hexaploid variety "Cachurulu" developed by Sanchez-Monge is released for commercial production.

Important Events in the Development of Triticale

	Canada	The "Rosner" strain, developed at the University of Manitoba and used by distillers since the early 1960s, becomes the first North American triticale released for general use.
1971	Mexico	International Development Research Centre and Canadian International Development Agency make a US$ 2.5 million grant to the CIMMYT/University of Manitoba program for a five-year research project.
	Mexico	"Maya 2/Armadillo" lines are developed to counteract the high rate of lodging in triticales.
1972	Mexico	CIMMYT begins intensive selection and breeding for grain plumpness associated with high fertility, and initiates efforts to broaden triticale's genetic base.
1974	Mexico	The five highest yielding triticales in the ITYN trials at 47 locations yield 15% more than the best bread wheat check variety.
1975	Mexico	Mexico releases its first triticale variety, "Yoreme."
1975	Mexico	The first stable, high test weight family, "Panda," is identified.

Appendix 3 (Cont'd)

Important Events in the Development of Triticale

1976	Mexico	"Beagle" and "Drira," two complete triticales, show high yield and adaptation similar to that of the "Maya 2/Armadillo" cross.
1979	Mexico	Mexico releases its second and third triticale varieties, "Cananea" and "Caborca." Interest in triticale starts growing in many countries.
1980	France	France releases its first triticale variety, "Clercal." It eventually becomes the number one triticale variety in France, the leading producer of the crop in 1986.
1982	Poland	"Lasko," the most widely grown triticale in the world today, is approved for release in Poland.
1985	Brazil	Brazil, the country possessing the greatest potential area for growing triticale, officially approves the crop's cultivation and releases two varieties.
1986		Triticale surpasses the one million hectare mark.

Source: Adapted from Wolff, A. 1975. Wheat x rye = triticale. CIMMYT Today. CIMMYT, Mexico, D.F. Additional information supplied by the CIMMYT triticale program.

Glossary

Cross derivative: progeny of a cross.

Diploid: having two sets of chromosomes. Rye genomic composition = RR.

Genome: a complete set of chromosomes.

Haploid: having a single set of chromosomes.

Hexaploid: species having six sets of chromosomes. Bread wheat genomic composition = AABBDD; that of hexaploid triticale = AABBRR.

Intergeneric hybrid: progeny of a cross between species of two related genera, such as *Triticum turgidum* var. *durum* by *Secale cereale*.

Interspecific hybrid: progeny of a cross between two species within the same genus, such as *Triticum turgidum* var. *durum* by *Triticum aestivum*.

Octoploid: species having eight sets of chromosomes. Octoploid triticale genomic composition = AABBDDRR.

Tetraploid: species having four sets of chromosomes. Durum wheat genomic composition = AABB.

The International Maize and Wheat Improvement Center (CIMMYT) is an internationally funded, nonprofit scientific research and training organization. Headquartered in Mexico, CIMMYT is engaged in a worldwide research program for maize, wheat, and triticale, with emphasis on food production in developing countries. CIMMYT is one of 13 nonprofit international agricultural research and training centers supported by the Consultative Group for International Agricultural Research (CGIAR). The CGIAR is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). The CGIAR consists of 40 donor countries, international and regional organizations, and private foundations.

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