Triticale improvement and production

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Foreword

Triticale, the first successful human-made cereal grain, was deliberately produced in 1875 by crossing wheat with rye. Since then, the evolution of this crop has been the topic of keen interest for many plant scientists. According to the vision of early scientists, triticale should combine the best characteristics of both parents: wheat's qualities for making various food products with rye's robustness for adaptability to difficult soils, drought tolerance, cold hardiness, disease resistance and low-input requirements. The early excitement and publicity associated with triticale may appear to have exceeded the actual development of the crop. However, considering the thousand years during which most present major crops – such as wheat and rice – have evolved under domestication compared to the few years and modest effort devoted to triticale, it could be argued that the results are quite remarkable. Modern triticale cultivars perform as well as the best common wheat cultivars wherever scientific research has been sustained. Furthermore, in certain types of marginal soils, triticale cultivars outyield the best wheat cultivars. For instance, research results in the drought-prone regions of North Africa have shown that triticale can be an excellent alternative crop to wheat and barley. In cold, wet environments, the highly productive winter-type triticale cultivars developed primarily in Poland are continuously expanding into most cereals-based systems in Northern Europe.

Almost 3 million ha of triticale are grown today in the world. Triticale country reports presented in this book clearly indicate that today this crop is accepted worldwide with its area expanding significantly, particularly in stress-prone ecologies. Data on cultivar release and area are imprecise due to the lack of information from some National Agricultural Research Systems (NARSs) and sometimes due to the confidentiality required by the private sector. Present information available at the International Maize and Wheat Improvement Center (CIMMYT) shows that since the mid-1970s more than 200 cultivars have been released in more than 30 countries.

Initial problems related to low seed fertility and seed plumpness have been solved, and most current research focusses on improving grain quality for various food and feed uses and on improving adaptation to new areas. Food uses include bread, noodles, soft-wheat type products and malting. New alternatives for diversification have also emerged with the development of winter-type cultivars with higher forage biomass than spring cultivars. With these types, a substantial amount of biomass is available for grazing, cut forage, dual-purpose cultivation (first grazing or cut, then left for grain production), silage and hay production.

Triticale can certainly play a significant role in alleviating poverty for many needy families in some developing countries. Of particular interest is its good performance in stress environments and its diversified uses. However, as for any other crop, research efforts are still needed to improve adapted germplasm and determine best-crop management practices for these difficult areas. This will necessitate the interventions of many key players. In this context, this book presents state-of-the-art triticale production in the world. The first chapter gives a comprehensive overview of the history and evolution of triticale since its creation, whereas authors in the second chapter present the improvements accomplished at CIMMYT where the largest triticale breeding programme in the world is hosted. The world and agro-ecological level distribution of triticale, as well as its management as a crop, is covered in chapter three. The book examines extensively the actual and potential uses of triticale products in human and animal diets in chapters four and five. It also presents marketing strategies developed by the private sector, including practical examples on how triticale can compete with other cereal crops, in chapter six. Finally, the last section of the book presents the current situation of triticale production and research status in 13 countries, covering a very wide range of economic and scientific levels. Some of these country reports may be used as a model for those countries that are still in the embryonic stages of developing triticale technology.

While this book presents updated information on various aspects of triticale production, improvement, uses and marketing strategies in the world, it shows clearly that triticale potential has yet to be exploited and that most of its future success depends on efforts and resources allocated to research and development. Realizing this potential, the Food and Agriculture Organization of the United Nations (FAO) has rightly decided to bring out this publication hoping it will motivate researchers and policymakers' commitment to the further development of triticale in developing countries to enhance choices for farmers to diversify, increasing the income and sustainability of relevant production systems.

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The history and evolution of triticale

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In the first-ever published report describing a fertile hybrid between wheat and rye, Carman (1884) stated: "What do they promise! If the hybrids give us a grain less valuable than wheat or rye, nothing will be gained in this case, except the curious fact that a cross between two different genera of grain is possible." While the ambitious objective of creating a crop that combines all of the best attributes of wheat and rye in a single plant has not been fully realized, the overall attributes of today's triticale provides it with enough competitive advantages for it to be increasingly grown around the world. Judging from the close to 3 million ha of triticale grown today (FAO, 2003), one could easily argue that the descendants of hybrids between wheat and rye have delivered on their promise to provide humankind with another valuable cereal crop. Wherever intensive breeding efforts have been sustained, modern triticale cultivars are on a par with the best common wheats in terms of their yield potential under favourable conditions and are often more productive than most wheats when planted in different types of marginal soils. This result in itself is quite remarkable if one considers the very short history of triticale and the relatively modest investments in research to improve this species compared to other crops such as wheat.

The purpose of this chapter is to provide a chronological review of the important historical events that have shaped the evolution of triticale from a 'botanical curiosity', as it is often referred to in the literature, to a commercially viable and competitive agricultural crop.

GENOMIC STRUCTURE

Genetically, triticale (X *Triticosecale* Wittmack) is an amphiploid species stably baring the genomes of wheat (*Triticum* sp.) and rye (*Secale* sp.). By definition, the original or 'primary' triticales are the fertile, true-breeding progenies of an intergeneric hybridization, followed by chromosome doubling, between a seed parent from the genus *Triticum* and a pollen parent from the genus *Secale*. The great majority of today's triticales are descendants of primaries involving either common wheat (*Triticum aestivum* L., 2n=42=AABBDD) or durum wheat (*Triticum durum*, 2n=28=AABB) as the seed parent and cultivated diploid rye (*Secale cereale* L., 2n=14=RR) as the pollen parent. Hexaploid wheat-derived primaries, referred to as octoploid triticales (2n=56=AABBDDRR), were the first to be produced and extensively studied. However, in spite of very valuable breeding efforts during the first half of the twentieth century, they did not spread as cultivars to any substantial extent. Since the early 1950s, and to a greater extent during the last 40 years, the bulk of the breeding and research efforts has focussed on developing and improving hexaploid triticales (2n=42=AABBRR), amphiploids originally made between tetraploid wheat and diploid rye. Consequently, the majority of triticale grown worldwide today consists of hexaploid types. However, as will be discussed in the following sections, octoploid triticales have contributed greatly to the improvement of hexaploid types.

The creation of new species through allopolyploidization is certainly not specific to triticale. This process has marked the evolution of several plant species and has provided humankind with its most important food crop, wheat, which combines the genomes of two or three ancestral grass species, brought to thrive together harmoniously within the same cell through thousands of years of natural and human-driven selection. What makes the history and evolution of triticale as a species so unique compared to that of wheat or other allopolyploids is that its evolution occurred during the last 114 years (the first 'true' triticale according to today's definition was bred in 1888 by the German breeder Rimpau) and its most dramatic evolutionary events (i.e. allopolyploidization as a result of intergeneric hybridization followed by chromosome doubling) were almost all directed by humans. In this sense, the history of triticale is truly a striking statement in support of Vavilov's definition of plant breeding as "… evolution directed by the will of man" (Vavilov, 1935, cited in Briggs and Knowles, 1967). Furthermore, in the case of triticale, it would be appropriate to state that its evolution as a crop was almost entirely directed by the unwavering will of a few people. Given the competitiveness of modern triticales among other small grains, future breeders or agriculturalists may easily forget that the development of triticale was paved with many failures, disappointments and frustrations. It did indeed take the strong will of a handful of people to overcome what many scientists regarded as insurmountable biological barriers and to persevere in spite of the disappointing performances of the early triticales and the resulting scepticism of much of the scientific and agricultural communities. The short but fascinating history of triticale is best summarized by quoting Dodge who wrote: "Triticale is a product of a century of dreams and forty years of active pursuit of the all-but-impossible" (cited in National Research Council, 1989). However, one also needs to recognize that its history and rapid evolution were markedly shaped by fortunate natural events occurring at very critical moments. Two such events are rather remarkable and therefore will be discussed below in some detail.

THE FIRST HUMAN-MADE WHEAT-RYE HYBRIDS

The first report describing the production of hybrid plants between wheat and rye (among other combinations between pairs of different cereals and grasses) was presented to the Botanical Society of Edinburgh, Scotland, by the botanist Wilson in 1875 (Wilson, 1875). He succeeded in obtaining plants with attributes intermediate between those of the two parental species. Both plants were completely sterile as they produced completely dysfunctional pollen grains. Wilson concluded his report by writing: "…[the author] presumes to submit his observations for what they are worth to those who may intend going further into the subject".

In the 30 August 1884 issue of the *Rural New Yorker*, Carman published the first-ever illustration of a partially fertile wheat-rye hybrid plant. Not aware of Wilson's experiments, Carman made a controlled cross in 1883 between Armstrong wheat (a popular, awnless variety that, according to Leighty [1916], was later called Martin Amber) and an unidentified rye, which resulted in ten seeds. Of the nine seeds that germinated, eight produced fertile plants that "resembled wheat", while only one exhibited some rye traits and was only partially fertile. In his study of Carman's records, Leighty (1916) rightly concluded that the latter plant was the only possible "true" hybrid while the other eight must have been the result of pollination by wheat in spite of all the precautions taken during crossing. Interestingly, Carman went ahead and attempted to market progenies from these plants, erroneously advertised as wheat-rye hybrids. These varieties, named RYN No.2-Willits and RYN No.3-Roberts, were never cultivated to any significant extent. Even before Leighty's review of Carman's work (Leighty, 1916), the Australian breeder Farrer (1898) had expressed strong doubts as to RNY No.2-Willits having any trace of "rye blood". On the other hand, the nearly sterile plant and only probable true wheat-rye hybrid produced extremely variable progenies. Selection efforts within the resulting populations were not successful in completely fixing all observable traits. Nevertheless, a variety called RYN No.6 was apparently released from these selections and was even grown commercially to a certain extent, at least until the year Leighty (1916) published his account of Carman's work. In light of these accounts, it is very doubtful that Carman ever produced a true-breeding, stable wheat-rye amphiploid.

In 1888, the German breeder Rimpau (reported in Rimpau, 1891) performed a series of crosses between wheat and rye, which resulted in a unique, partially fertile true-hybrid plant baring 15 seeds. Three of these produced completely sterile plants, while the remaining 12 yielded fertile plants. Unlike the progenies of Carman's hybrid, those from Rimpau's hybrids were uniform in their appearance, resembled the mother F_1 plant, and most importantly, were true breeding throughout many subsequent generations. At the time Rimpau published his results, he probably did not realize the significance of his achievement, namely, that he had just produced the first stable amphiploid between wheat and rye – the first triticale – and that he had witnessed the origin of the first new cereal species. More than 45 years later, Linschau and Oehler (1935) and Müntzing (1935, 1936) established that the somatic cells of seedlings from the stable Rimpau strain had an average of 56 chromosomes as would be expected from an octoploid amphiploid between hexaploid wheat and diploid rye. Tschermak, according to whom this strain had been cultivated for more than 40 years at the garden of the Agricultural University of Vienna (Tschermak-Seysenegg, 1936, cited in Müntzing, 1979), provided the seed studied by Müntzing. Prior indication of the amphiploid nature of the Rimpau strain was provided by Moritz (1933), whose serological analyses identified protein components from both parental species.

Several other early attempts at producing artificial wheat-rye hybrids or exploiting natural wheat-rye hybrids identified in experimental plots were reported during the first two decades of the twentieth century. All of these either produced no hybrid seed at all or, when very few seeds were obtained, they were shown to be the result of an out-crossing with wheat (or rye to a lesser extent) pollen (see Briggle, 1969 and Lorenz, 1974 for a review of these events).

EARLY BREEDING WORK WITH OCTOPLOID TRITICALE PRIMARIES

Although the history of the development of triticale was mostly human-driven, nature did help, at least in two critical instances. One such instance was the mass appearance of natural wheat-rye hybrids in experimental plots at the Saratov Experiment Station in the southeastern Russian Federation in 1918, which provided Meister and his group abundant raw material (thousands of plants) to start an extensive botanical, cytological and agronomical characterization of wheat-rye hybrids. The resulting series of studies conducted from 1918 to 1934 by Meister and his co-workers, as well as by others inspired by the Saratov event, were instrumental in understanding the cytological basis and requirements for the production of the ancestors of triticale, or "wheat-rye hybrids of balanced types" as they were referred to at the time. First, it was shown that F_1 wheat-rye hybrids were incapable of self-pollination, and if any seed was produced, which would be a rare event, it would be the result of pollination by wheat or rye and the progenies of such an out-cross would segregate for both wheat and rye attributes (Meister, 1921). However, the most significant event reported later (Meister, 1928, 1930; Tiumiakov, 1928, 1930; all cited in Müntzing, 1979) was the identification and description of fertile, true-breeding hybrid derivatives with a phenotype intermediate between wheat and rye (much like Rimpau's hybrid), which were presumed to be allopolyploids. Meister (1930) also proposed the name of *Triticum secalotricum saratoviense* Meister to designate the "balanced-type hybrids". Conclusive evidence of the amphiploid/octoploid nature of the "balanced-type hybrids" identified by Meister came in 1930 as a result of a cytological analysis performed by Lewitsky and Benetzkaja (cited in Müntzing, 1979), which demonstrated a somatic chromosome number of 56 and provided the first-ever picture of what would be an octoploid triticale karyotype. These researchers also were the first to report on the general tendency for amphiploids to exhibit a disturbed pairing at meiosis (in both the male and female side) resulting in the formation of univalents, or unpaired chromosomes.

By 1934, with the increasing influence of Lysenko on the agricultural research scene in the former Soviet Union, most of the work on triticale had stopped at Saratov (Zillinsky, 1974).

Fortunately, the work of Müntzing at Svalöv, Sweden, and of Oehler and co-workers at Münchenberg, Germany, kept the research on wheat-rye amphiploids alive and resulted in the first breeding efforts to improve the agronomic attributes of early octoploid triticales. As outlined earlier, both groups provided evidence for the amphiploid nature of the Rimpau hybrid (Lindschau and Oehler, 1935; Müntzing, 1935, 1936) thereby setting a clear record regarding the creation of triticale as a species. Incidentally, one additional contribution of the Oehler group was to use, for the first time, the name 'triticale' to designate their wheat-rye amphiploids (Lindschau and Oehler, 1935), reportedly following a suggestion from Tschermak.

Several cytogenetic mechanisms have been proposed, by which a mostly sterile F_1 hybrid between wheat and rye could spontaneously produce fertile amphiploids (van der Berg and Oehler, 1938, cited in Lorenz, 1974). In 1935, Müntzing carefully examined 65 F_1 hybrid plants representing 15 wheat-rye combinations and revealed the presence of a few partly dehiscing anthers in two plants belonging to the same cross combination. Twenty to 60 percent of the pollen grains produced in the dehiscing anthers were apparently normal and probably contained un-reduced chromosomes as indicated by their large size. Through controlled pollination using this pollen, Müntzing was able to obtain a new amphiploid plant baring 56 chromosomes. Based on these results, he suggested that the mechanism by which the early spontaneous amphiploids were produced was the spontaneous formation of a small somatic sector, which includes anthers and ovules or a small area in the anther, with a doubled chromosome number (Müntzing, 1936).

During the mid-1930s and in later decades, Müntzing started intercrossing primary octoploid triticales (those developed in Sweden as well as some introduced from other countries) and crossing these with common wheat with the objective of improving the agronomic attributes of octoploid triticale. While progenies of such crosses were clearly superior to their parents, they were still inferior to wheats in their yield potential, mainly due to their partial sterility, tendency to lodge, shrivelled kernels and susceptibility to sprouting. In light of these results, the future of triticale as a crop appeared quite bleak all through the late 1930s and 1940s.

A breakthrough came with the development of a method to double plant chromosomes using colchicine, a chemical isolated from the autumn crocus (Blakeslee and Avery, 1937). However, although many new octoploid primaries could be produced easily without having to rely on rare spontaneous doubling as described above, the use of colchicine in the end was more beneficial to the development of hexaploid triticale towards which international attention was turning. After a lifetime working on octoploid triticales, Müntzing (1979) admitted: “It is possible that the interest in triticale as a potential new crop would have tapered off completely if the efforts had been limited to octoploid material. However, this was successfully prevented by an enormous development of work with hexaploid triticales.”

DEVELOPMENT OF THE FIRST HEXAPLOID TRITICALES: THE BASIS FOR COMMERCIAL SUCCESS

As for octoploid types, hexaploid triticale development started with the production of non-amphiploid hybrids (Jesenko, 1913; Schegalow, 1924, cited in Müntzing, 1979). The first report of a true amphiploid was that of Derzhavin (1938), which involved cultivated durum wheat and a wild species of rye, *Secale montanum* (cited in Zillinsky, 1974). Hexaploid primaries that would play a more important role as starting material for breeding programmes in North America and Europe were those resulting from crosses between cultivated tetraploid wheats and cultivated rye. Their production was greatly facilitated by the availability of colchicine and the improvement of techniques for embryo culture on artificial media (to rescue embryos from non-compatible combinations that would otherwise starve and produce no seed). O’Mara produced the first of such primaries in 1948 at the University of Missouri, United States of America (O’Mara, 1948), soon followed during the early to late 1950s by Nakajima in Japan (Nakajima, 1950), Sánchez-Monge in Spain (Sánchez-Monge, 1959), Kiss in Hungary (Kiss, 1971) and Pissarev in eastern Siberia, Russian Federation (Pissarev, 1966). Driven by the belief that hexaploid triticale would be superior to its octoploid counterpart, these researchers produced numerous hexaploid primaries that finally represented a much wider genetic base than that produced for octoploids.

In 1954, a privately endowed research chair was established under the initiative of Shebeski at the University of Manitoba, Canada, with the explicit objective to develop triticale finally as a commercial crop. Under the leadership of Jenkins and Evans, the breeding and cytogenetics programme assembled a comprehensive collection of primary triticales from all over the world and, in 1958, started intercrossing these stocks and selecting improved recombinants while continuing the production of new primaries (hexaploids as well as octoploids). This work was implemented for the development of both winter and spring triticales.

Probably operating on a smaller scale, the Hungarian effort headed by Kiss and the Russian effort lead by Pissarev were to become important to the success of triticale because of their crosses between octoploid and hexaploid types that resulted in progenies with greatly improved agronomic attributes compared to their parental stocks (Kiss, 1971; Pissarev, 1966). By the late 1950s, the production of secondary hexaploid recombinants from crosses between octoploid and hexaploid triticale had become a widely used method in triticale improvement, including the University of Manitoba programme (Jenkins, 1969). According to Zillinsky (1974), octoploid triticales have contributed to the progeny of such crosses through improved meiotic stability and fertility, plumper seed, lower amylase activity and higher lysine content.

After producing his own hexaploid and octoploid primaries using local varieties of wheat, *Triticum turgidum,* and rye, Kiss made his first octoploid x hexaploid cross in 1954. By 1960, he obtained secondary hexaploid recombinants that were clearly superior to either parental type, except for their weak straw. According to Müntzing (1979), one such progeny, designated as Triticale No.30, was grown on some farms, but its lack of straw strength prevented its release to wider commercial production. Undeterred by such a setback, Kiss continued improving his material using octoploid x hexaploid crosses until he obtained two selections, Triticale No.57 and Triticale No.64, which were included in National Yield Trials in 1965 (Zillinsky, 1974). In 1968, Triticale No.57 and Triticale No.64 were the first-ever triticales to be released for commercial production, and a year later they were grown on 40 000 ha in Hungarian farmers’ fields.

In 1969, the Canadian programme released its first commercial cultivar, Rosner, a spring type that demonstrated good potential as a raw product for the feed, brewing and distilling, and breakfast cereal industries. The same year, the first Spanish cultivar, Cachurulu, was released, but its adoption was hampered by its susceptibility to lodging, difficulty in threshing and lack of bread-making quality (Sánchez-Monge, 1973).

While these programmes had the undeniable merit of making triticale a commercial reality in their own countries, they developed material adapted to very specific agro-ecological environments, which collectively represented a rather minor fraction of the small-grain areas worldwide. Consequently, the global spread of triticale would have had to occur through the establishment of many breeding efforts worldwide, at least one in each country interested in taking advantage of the potential of this promising new crop. This was not the case thanks to the involvement of the International Maize and Wheat Improvement Center (CIMMYT). In addition to its global mandate to develop improved wheat and maize germplasm for the world, CIMMYT rapidly became an “international base for triticale breeding”, starting in the early 1960s.

CIMMYT’S SPREAD OF SPRING TRITICALE THROUGH BREEDING FOR GLOBAL ADAPTATION

The International Maize and Wheat Improvement Center was officially founded in 1966 with Mexico as its base. Triticale research in Mexico started a few years earlier under its parent organization, the Office of Special Studies of the Rockefeller Foundation under the leadership of Norman E. Borlaug. According to Zillinsky (1974), Borlaug started believing in the potential productivity and nutritional values of triticale that could improve human nutrition in food-deficient areas after he observed the breeding material at the University of Manitoba in 1958. Although the plants left much to be desired, he thought that triticale improvement could be substantially accelerated if breeders could benefit from two crop cycles in the same year, as was the case for wheats in Mexico. Soon, the triticales from Manitoba started appearing in Mexico. The first of these lines were received in 1963 from Rupert from Chile, along with wheat populations (Zillinsky, 1974), and were immediately crossed to several Mexican dwarf, day-length insensitive wheats by engineers Rodriguez and Quiñones, reportedly out of mere scientific curiosity. In 1964, the Rockefeller Foundation funded a collaborative project between Borlaug’s Mexican programme and the University of Manitoba with the objective of “developing a grain crop that would be competitive with other cereals, particularly in improving human nutrition in developing countries” (Zillinsky, 1974). First led by Borlaug until 1966, the CIMMYT triticale research programme was taken over by Zillinsky in January1968. He became the first full-time triticale breeder of this organization and remained in that position until 1982.

To reach their objective, the Canadian and Mexican groups intended to use the extensive germplasm base produced and/or collected at the University of Manitoba in crosses with the Mexican photoperiod-insensitive dwarf wheats, or primaries based on these, and subject the resulting segregating populations to a shuttle-breeding scheme involving selection under three strikingly different environments. During the winter cycle, triticale material was grown in the state of Sonora, Mexico, near Ciudad Obregón (at an experiment station of the Mexican Centro de Investigaciones Agricolas del Noroeste, CIANO) located at 28°N and at an elevation of 35 masl. This is a location with almost no rainfall during the crop cycle, where irrigation is essential but where high yields are generally achievable. The main disease is leaf rust, and the plants develop with increasing day-length. Material selected and harvested in Sonora was immediately send for planting during the summer cycle some 1 800 km south, in the state of Mexico near Toluca. The latter is a high-rainfall location situated at 18.5°N and at an altitude of 2 600 masl. The Toluca Valley is a heaven for several fungal diseases including yellow rust and those caused by *Septoria* sp. and *Fusarium* sp. During this cycle, plants develop with decreasing day-length. Differences in soil types and pH are also substantial between these two locations, with Ciudad Obregón having rather alkaline soils and Toluca showing various levels of acidity. In addition to these remarkably contrasting selection sites, material was sent during the summer cycle to near Winnipeg, Manitoba, Canada (50°N, 230 masl).

With the doubling of selection cycles each year, the tripling of the number of selection sites and the contrast between these, the access to a wide range of day-length insensitive and widely adapted wheat germplasm and the increased human and financial resources devoted to its improvement, triticale would finally be in a position to become a globally adapted crop. In 1967, after four cycles of selection using the shuttle-breeding scheme on populations from the first crosses, disease-resistant, advanced lines with enough day-length insensitivity were compared in replicated yield trials to the best CIMMYT dwarf wheats. However, even with such an apparently powerful set-up, these first results were much less than encouraging as the best triticales yielded about half as much as the common wheats (Zillinsky, 1974). Poor performance was attributed to excessive height, late maturity, high incidence of sterility and severe seed shrivelling, while the total biomass production in the triticales was at least as good as in the best wheats.

During the following cycle of 1968 and without dwelling much on the disappointing results, Zillinsky and his collaborators focussed their selection efforts on finding plants (among the hundred of thousands planted) with improved fertility. In this huge ‘haystack’ of plants, they indeed found some that would turn out to be the ‘needles’ for which they were looking. A few F_4 plants from the cross designated as x308 between two hexaploid triticales exhibited what they considered improved fertility (15 percent seed-set above the best original hexaploid according to Zillinsky [1974]). Advanced progenies of these plants, subsequently named Armadillo, exhibited much more than improved fertility. They were characterized by higher test weights and grain yields and enhanced day-length insensitivity compared to the previously bred lines. They also were early maturing, shorter in stature with one gene for dwarfness and had good nutritional quality (Zillinsky and Borlaug, 1971). Also of great importance was the observation that all of these improvements were readily transmitted to the progeny of crosses involving Armadillo and that the latter was more readily crossable to common or durum wheat or rye.

The appearance of Armadillo came at a highly critical time – as the first evaluation of the products from the CIMMYT/University of Manitoba effort revealed very disappointing results – and has probably been instrumental in keeping triticale breeding alive at CIMMYT as well as the hopes for triticale to ever become a global cereal crop. Although the CIMMYT breeders of that time can be credited with several outstanding achievements, the advent of Armadillo was not of their doing. This event was in fact one of the two acts of nature, mentioned previously in this chapter, that would bare great significance on the history and evolution of triticale as a crop. Armadillo was shown to be the product of a natural out-cross between the F_1 hybrid of cross x308 and an unidentified dwarf common wheat. Nonetheless, CIMMYT breeders took full advantage of this fortunate event, and by the end of 1970, Armadillo was in the pedigree of virtually every advanced line. Later, Gustafson and Zillinsky (1973) demonstrated that Armadillo retained chromosome 2D from wheat and lost chromosome 2R from rye; and it became the primary example of what are referred to as 'substituted' triticales (one or several chromosomes of the rye complement substituted by the same number of chromosomes from wheat) as opposed to 'complete' triticales (lines possessing all seven rye chromosomes).

The International Triticale Yield Nursery (ITYN) was distributed for the first time in 39 locations worldwide in the 1969/70 crop season, providing the first opportunity to assess the yield potential and adaptability of triticale on a global scale. According to Zillinsky (1974, 1985), results were again disappointing, and the first lines distributed (including some Armadillo lines) were more narrowly adapted than the regular CIMMYT wheats (Mackenzie, 1972). However, noticeable progress became evident starting from the second and third ITYNs and continued steadily thereafter.

One characteristic the Armadillo lines did not provide was resistance to lodging and the ability to withstand high nitrogen input, which explained the persisting gap in grain yield between the best triticales and the elite dwarf wheats. Resistance to lodging through shorter straw, as well as increased yield and test weight and wider adaptation, were obtained with the cross between an octoploid primary called Maya 2 (based on semidwarf wheat INIA 66) and Armadillo. These lines (collectively called M2A) made their appearance in the fifth ITYN in 1973/74, which was grown at 47 locations worldwide. For the first time, the yield of the top five triticales outyielded by 15 percent the bread wheat check (Varughese, Baker and Saari, 1987). In 1977/78, the average yield over 71 locations of Mapache, one of the lines from the M2A cross, was higher than that of any of the 50 best CIMMYT bread wheats included in the International Spring Wheat Yield Nursery (ISWYN) (Zillinsky, 1985). To date, a total of 19 cultivars have been released worldwide from the M2A cross (Skovmand, Mergoum and Pfeiffer, 1998).

By the mid-1970s, the gap in yield between spring wheat and spring triticale had been closed, and the global adaptability of spring triticale had been established, merely 15 years (30 selection cycles) after the first triticale cross was made in Mexico. The challenge of making spring triticale a globally adapted commercial crop, competitive with other small-grain cereals, had been won.

In light of the success of the M2A lines, which like Armadillo are substituted triticales, one could have easily thought that the presence of one chromosome from common wheat would be necessary for triticale to be competitive with wheats and base a selection programme on this assumption. However, improvement of the complete types was wisely continued and resulted in the development in 1976 of two groups of lines, namely Drira and Beagle, which soon demonstrated to be as competitive and widely adapted as the M2A lines (Varughese, Baker and Saari, 1987). In fact, there is a body of evidence from analyses of data from international nurseries that indicates similar performance of both types under favourable conditions, but a clear superiority of complete types over substituted types under many forms of stress conditions (limited water availability, acid soils, nutrient deficiency or toxicity and high disease pressure) or in marginal lands (Varughese, Pfeiffer and Peña, 1996).

Between 1975 and 2000, the global distribution of CIMMYT spring triticales through its international nurseries resulted in the release for commercial production of 146 cultivars in 23 countries across five continents. In addition, encouraged by the successful establishment of spring triticale worldwide, some countries started local breeding efforts, producing their own primaries and often crossing them with CIMMYT lines, with the objective of developing material with greater specific adaptation to their own environments or to address local market requirements. Such efforts were started in Australia, Brazil, Portugal and India (development of white-grain types), just to name a few.

LARGE-SCALE EXPANSION OF WINTER TRITICALE

Whereas the area sown to spring triticales has become more and more important and involved an increasing number of countries as a result of the CIMMYT work, the majority of the world's triticale area is still sown to winter or more or less facultative types. This expanding area of winter triticale is concentrated mainly in Northern Europe and North America.

After his pioneering work opened the door for the commercial use of triticale, Kiss had to phase out his activities in Hungary in 1970. Promoting international cooperation between the countries of the former Eastern Block under Soviet influence, state officials decided that Poland was better suited for triticale research than Hungary, and Kiss was forced to transfer his breeding material to Polish scientists.

A little earlier, in 1968, Wolski and his collaborators had started an intensive winter triticale breeding effort making good use of Kiss's valuable germplasm. Much of their early work was based on triticale x hexaploid wheat crosses (Banaszak and Marciniak, 2002), culminating in their first release in 1982 of Lasko, which would become the widest grown triticale in the world. It was registered in eight countries in Europe, as well as in New Zealand. By 1986, a significant portion of the rye area in Poland, more than 300 000 ha, was replaced by triticale. The next year, with some 600 000 ha sown to triticale, Poland became the largest producer in the world. Today, Polish winter triticale cultivars are widespread all over Europe, North America and New Zealand, demonstrating competitiveness under a remarkably wide range of environmental conditions. Wolski and his collaborators have provided adapted material to several countries/regions that did not have intensive triticale breeding efforts and therefore have contributed substantially to the spread of the winter types and the resulting expansion of the area of triticale worldwide.

Other winter triticale improvement efforts have been conducted since the early 1960s in both Eastern and Western Europe; though none the size and success of the Polish programmes, they resulted in valuable material with adequate specific adaptation to the different agro-ecological areas they were targetting. Programmes in the Russian Federation, Ukraine, France, Romania and former Yugoslavia, to name a few, have yielded widely grown cultivars in each of these countries. By the mid-1980s, the success of all of these programmes, from a breeding standpoint, demonstrated that winter triticale could be bred to be competitive practically everywhere winter wheat is grown in Europe.

CONCLUDING REMARKS

This chapter has attempted to provide a chronological review of the history and evolution of triticale, from the first tentative steps towards its creation as a species to the most important events that have helped establish it as the successful commercial crop it is today. Whereas the competitiveness and wide adaptability of triticale are no longer questionable, its further expansion worldwide faces several types of challenges in the future.

From a breeding standpoint, the spectacular progress in yield and agronomic performance may have resulted in narrowing the genetic base of the triticale cultivars produced by the major breeding programmes around the world. If this trend is confirmed and nothing is done to counteract it, triticale might find itself in a vulnerable position, which might ultimately hamper its expansion. As its area grows, triticale is increasingly exposed to various pathogens, and the opportunities for these pathogens to produce physiological variants with severe virulence on major cultivars are enhanced accordingly. The identification, use and maintenance of as much genetic variability as possible for genes conferring resistance to various pathogens of economic importance needs to be ensured to prevent such potentially devastating genetic vulnerability.

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Triticale crop improvement: the CIMMYT programme

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Cereals are worldwide the most important cultivated crops and account for the main source of energy and protein in human and domesticated animal diets (Rajaram, 1995). Addressing the increasing demand for food in developing countries continues to be a major concern worldwide, due to the high population growth rates aggravated by natural calamities, such as drought, diseases and pest epidemics. Today, many developing countries rely on importing large quantities of wheat, rice, maize and barley to meet their food and feed grain needs (Curtis, 2002). Increasing national cereal production in these countries can be achieved through increasing average yield per unit area or expanding the area devoted to cereals into more marginal lands. Under these environmental conditions, an additional crop, which provides farmers with improved production alternatives, will make a significant contribution to farmers' income. Triticale (X *Triticosecale* Wittmack), the 'human-made' crop, developed by crossing wheat (*Triticum* sp. L.) and rye (*Secale cereale* L.), which is adapted to harsh, low-input, sustainable farming systems, is a viable alternative (Plate 1). Triticale, though a newly cultivated crop, is rapidly expanding in several production systems (Pfeiffer, 1994; Hinojosa *et al.*, 2002). Its ability to produce higher biomass and grain yield compared with other cereals over a wide range of soil and climatic conditions has enhanced its adoption in more than 30 countries. Triticale today is cultivated on nearly 3 million ha (FAO, 2003).

A BRIEF HISTORY OF TRITICALE AT CIMMYT

Triticale, the successful 'human-made' cereal grain, was first deliberately produced in 1876 and has developed during the last 100 years. Interest in triticale at the International Maize and Wheat Improvement Center (CIMMYT) dates back to 1958 when Norman E. Borlaug (at that time with the predecessor organization, the Office of Special Studies of the Rockefeller Foundation) attended the First International Wheat Symposium at the University of Manitoba, Canada. What became the CIMMYT Triticale Improvement Program started in 1964 under the leadership of Borlaug, followed by Frank J. Zillinsky in 1968 (Zillinsky and Borlaug, 1971). This programme, in cooperation with the University of Manitoba, was funded initially by the Rockefeller Foundation. In 1971, the Government of Canada undertook complete funding of the CIMMYT Triticale Improvement Program.

In the beginning, several major hurdles had to be overcome to tailor triticale to become a viable crop. Early triticales, though vigorous in growth habit, were extremely late, very tall, highly sterile, day-length sensitive and had shrivelled seeds. The first major breakthrough came by serendipity when a triticale plant resulting from a natural out-cross to unknown Mexican semidwarf bread wheat was selected in 1967. The selected line, named Armadillo, made a major contribution to triticale improvement worldwide since it was the first triticale identified to carry a 2D(2R) chromosome substitution (D-genome chromosome substitution for the respective R homeologue). Due to this drastic improvement in triticale germplasm, numerous cultivars were released, and the crop was over-promoted to farmers as a 'miracle crop'. This premature excitement disillusioned many farmers and scientists and hampered adoption of the crop (CIMMYT, 1976).

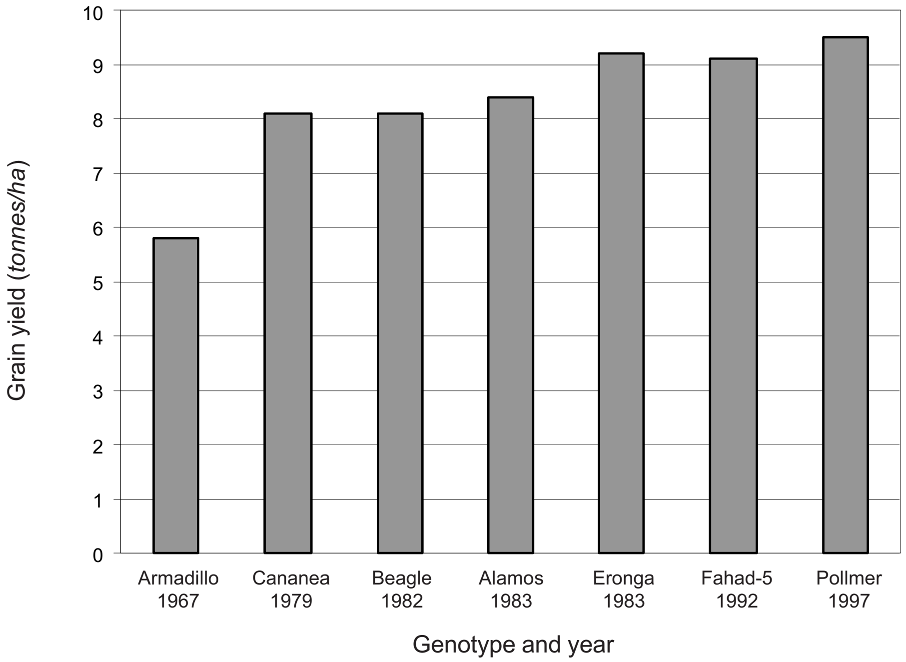
By the late 1980s, data from international yield trials indicated that complete hexaploid triticale (AABBRR genomic representation) was agronomically superior to 2D(2R) substituted hexaploid types, particularly under marginal growing conditions. Thereafter, triticale germplasm at CIMMYT was gradually shifted towards complete R genome types to better serve these marginal environments.

Today, CIMMYT is the principal supplier of improved spring triticale germplasm for many national agricultural research systems around the world. The spring material is also an ancestral constituent of most winter triticales.

MAJOR ACHIEVEMENTS OF TRITICALE IMPROVEMENT AT CIMMYT

Three decades of research on triticale by CIMMYT in collaboration with National Agricultural Research Systems (NARS) around the world have resulted in substantial improvements of triticale. Today, triticale is an accepted crop in many countries, and areas grown to this crop are expanding. In 2003, triticale occupied nearly

FIGURE 1
Genetic progress in grain yield of spring triticale at CIMMYT, 1967-1997; estimated genetic progress over period is 120 kg/ha/year



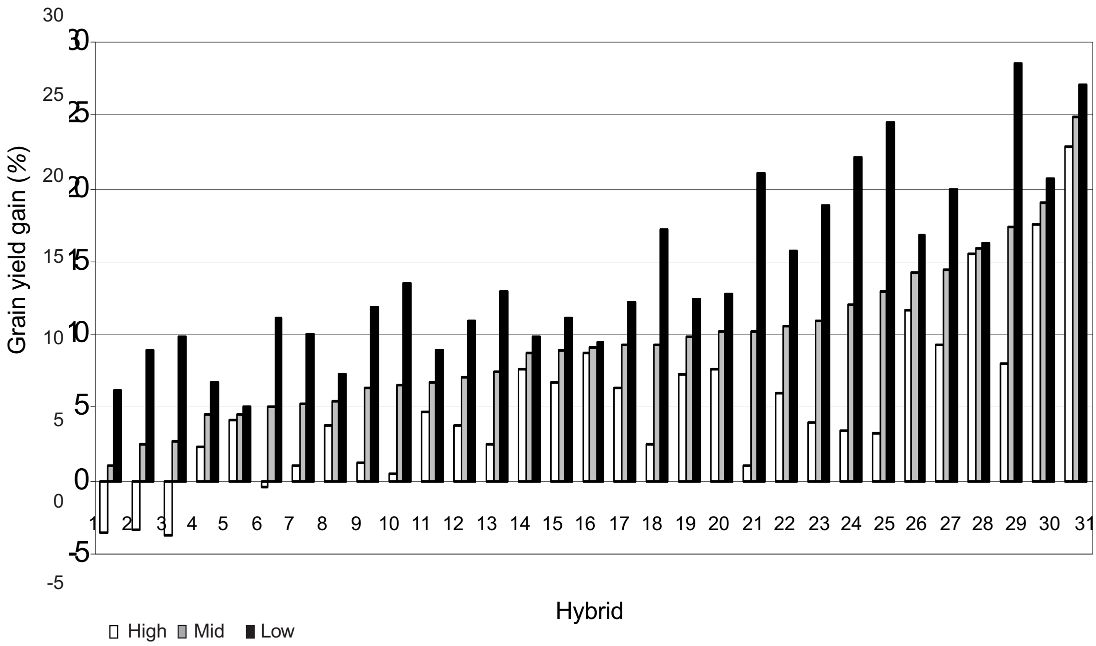
3 million ha worldwide, compared to about 1 million ha in 1988 (Varughese, Pfeiffer and Peña, 1996a; FAO, 2003). Ample evidence now exists showing that triticale has potential as an alternative crop for different end-uses in a wide range of environments, particularly for marginal and stress-prone growing conditions (Pfeiffer, 1995).

Since 1969, when CIMMYT first distributed triticale germplasm internationally, national programmes have released cultivars derived from this germplasm. Data on cultivar releases based on CIMMYT spring triticale germplasm are very sketchy due to the lack of information from some NARSs or the confidentiality required by the private sector. However, present information available at CIMMYT shows that since the mid-1970s more than 200 cultivars have been released in more than 30 countries from direct CIMMYT germplasm introductions (advanced lines) or through selection from segregating populations. Some releases from the newly distributed winter and facultative CIMMYT nursery (TCLWF) have been reported from several countries such as Mexico.

Yield potential

Since the establishment of the CIMMYT triticale breeding programme in 1964, improvement in realized grain yield potential has been remarkable. In 1968, at Ciudad Obregón, Sonora, Mexico, the highest yielding triticale line produced 2.4 tonnes/ha with a test weight of 65.8 kg/hl. Eleven years later under similar conditions, the best triticale line yielded 8.5 tonnes/ha with a 72 kg/hl test weight (Zillinsky, 1985). The yield potential of triticale continued to increase in the subsequent ten years of breeding at CIMMYT. Under near optimal conditions at Ciudad Obregón, a comparison of maximum-yield trials of triticale developed in the 1980s and 1990s revealed an average increase of 1.5 percent/year (Sayre, Pfeiffer and Mergoum, 1996). This yield progress was mainly due to a substantial increase in harvest index (16 percent), grains/m^2 (17 percent), spikes/m^2 (12 percent) and test weight (12 percent) and a decrease in plant height (11 percent). Hence, today's high-yielding CIMMYT spring triticale lines (e.g. Pollmer-2) surpassed the 10 tonnes/ha yield barrier under optimum production conditions at Ciudad Obregón (Figure 1) (Sayre, Pfeiffer and Mergoum, 1996). Obviously, compared to early developed triticale, the new strains are characterized by higher harvest index and test weight, significantly increased number of spikes/area and grains/spike and generally shorter stature (Pfeiffer, 1995; Sayre, Pfeiffer

FIGURE 2
Grain yield gains (heterosis) in percentage of low-, mid- and high-yielding parents of 31 spring triticale hybrids developed at CIMMYT using a chemical hybridizing agent under a high-input environment at Ciudad Obregón, Sonora, Mexico, 1995/96 and 1996/97



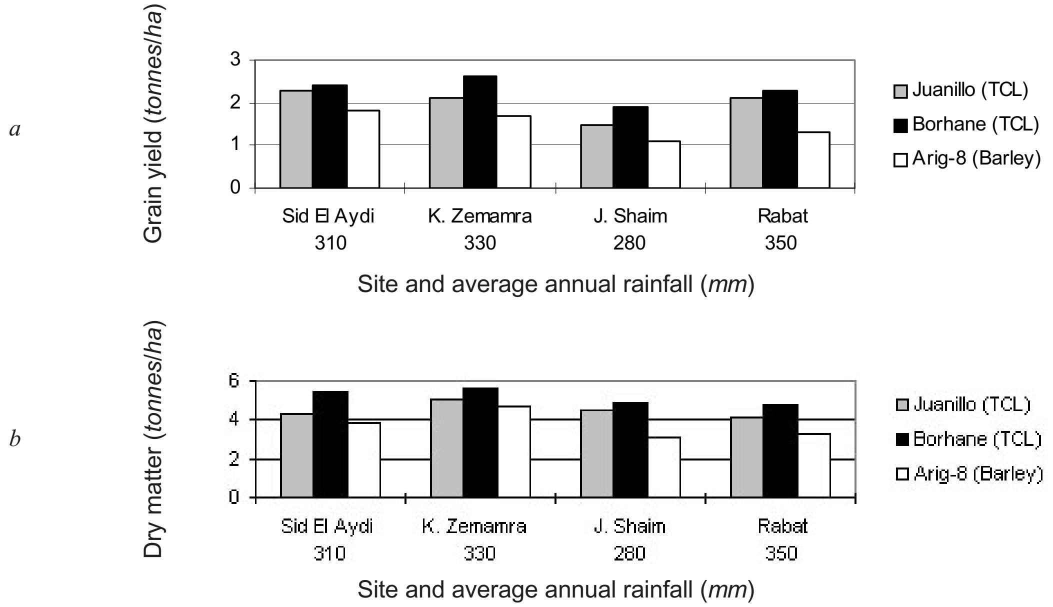
and Mergoum, 1996). Parallel progress was achieved in other essential agronomic production components, such as lodging resistance, early maturity and threshability, which is an important trait for smallholder farmers.

In recent years at CIMMYT, substantial research efforts have been devoted to exploring the utilization of triticale hybrids as a new way to enhance and 'break' the yield barrier. Several hybrids produced via chemical hybridizing agents (CHA) were evaluated for their agronomic performance and physiological traits under full-irrigated conditions at Ciudad Obregón (Figure 2). Grain yield distributions for the hybrids showed substantial heterosis for grain yield, up to 27 percent of the high parent. Hybrids, which yielded less than the low parent, had in general very high biomass, but the harvest index was low due to excessive plant height and late maturity. The cytoplasmic male sterile (CMS) system is also being explored as a sustainable way to produce hybrids in developing countries.

Adaptation

Germplasm expressing high, stable yields as a result of input efficiency and responsiveness, and resistance to a wide range of biotic and abiotic stresses is a hallmark of CIMMYT's cereal improvement philosophy (Rajaram *et al*., 1993). Hence, the development of triticale with wide adaptation over a large range of environments has been a major objective of the CIMMYT Triticale Improvement Program. Triticales, particularly those with a complete R genome, exhibit a competitive yield advantage in marginal lands, which are afflicted with abiotic stresses, such as low and erratic rainfall, soil acidity, phosphorus deficiency, trace element toxicity or deficiency and shallow marginal soils. These triticales also perform well in crop situations where diseases, insect pests and weeds constitute biotic production constraints. Hence, elite germplasm selected from advanced CIMMYT germplasm has shown since the early 1980s (e.g. Beagle, Eronga, etc.) and with the latest selections (e.g. Rhino 's', Bull/Manatti, Fahad-5, Pollmer, etc.) improved adaptation and good performance in contrasting environments. Similarly, early maturity, a typical characteristic of substituted triticale and many new complete lines, allows escape from terminal developmental stress, such as heat or frost, in highly productive environments, such as the irrigated subtropics and Mediterranean climates. Maturity differences between complete and substituted types are now smaller.

FIGURE 3
Performance in grain yield (a) and dry matter (b) of new triticale Borhane versus old triticale Juanillo and barley Arig-8 in four sites of the arid and semi-arid zones of Morocco; yields are relatively low in Rabat, Morocco, due to sandy soils with very low water retention that prevail in the costal region compared to other dryland sites



Under marginal land conditions, where abiotic stresses related to climatic (drought, extreme temperatures, etc.) and soil conditions (extreme pH levels, salinity, trace elements deficiency or toxicity, etc.) are the limiting factors for grain production, triticale has consistently shown its advantages compared to the existing cultivated cereal crops (Figure 3). Data, reports and experience from the arid and semi-arid regions of North Africa, for instance, have shown that triticale is an excellent alternative crop to the other cereals, particularly wheat and barley (Plate 2) (Belaid, 1994; Mergoum, Ryan and Shroyer, 1992; Saade, 1995; Varughese, Pfeiffer and Peña, 1996a). Since its cultivation is similar to traditional grown barley or wheat and it offers many more end-use alternatives for both humans and animals, triticale can be grown in stressed environments with low input for grazing, grain and straw production. In addition, in the relatively high-input areas (irrigated and high-rainfall regions), it can be used as forage or for dual purposes.

Similarly, under acid soils, such as in southern Brazil, triticale has demonstrated high tolerance to low pH levels. This enables the crop to be grown on relatively extensive areas, estimated at 130 000 ha in 2001 (do Nascimento Junior *et al.*, 2002), mainly in the southern regions of Rio Grande do Sul, Paraná and Santa Catarina. New promising triticales combining higher yield and other desirable traits (test weight, scab tolerance, early maturity, etc.) have been identified among modern CIMMYT germplasm, or its derivatives have been identified by national scientists, to replace or complement the existing cultivated cultivars.

Input-response efficiency

Response to input, such as nutrients or water, is a key element for triticale to be adopted by farmers, particularly under marginal conditions. Significant progress has been made in developing input-efficient triticales. Under high-input conditions, CIMMYT early developed triticale variety Beagle (1980s) compared with the later advanced line Fahad-5 (1990s) showed significant differences in grain yield under varying nitrogen (N) levels (Figure 4). Whereas Beagle yields were significantly lower than average triticale yields, Fahad-5 produced more grain than average for all N treatments. Yields of both cultivars at 0, 75, 150 and 300 kg/ha N were 1.3 and 1.6, 4.3 and 5.0, 5.3 and 7.0, and 6.0 and 7.5 tonnes/ha for Beagle and Fahad-5, respectively (Sayre, Pfeiffer and Mergoum, 1996). The yield differences between the two cultivars increased drastically with the N level applied. These results demonstrate clearly the substantial genetic

FIGURE 4
Grain yield response of new Fahad-5 versus old Beagle CIMMYT-developed triticales to nitrogen levels under high-input conditions at Ciudad Obregón, Sonora, Mexico

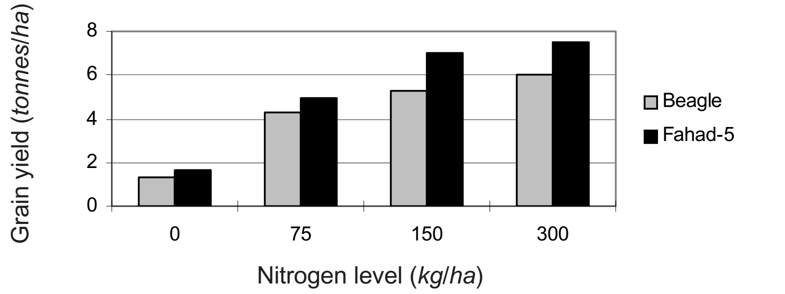


FIGURE 5
Triticale grain yield and straw dry-matter response to nitrogen levels under drought conditions in Morocco

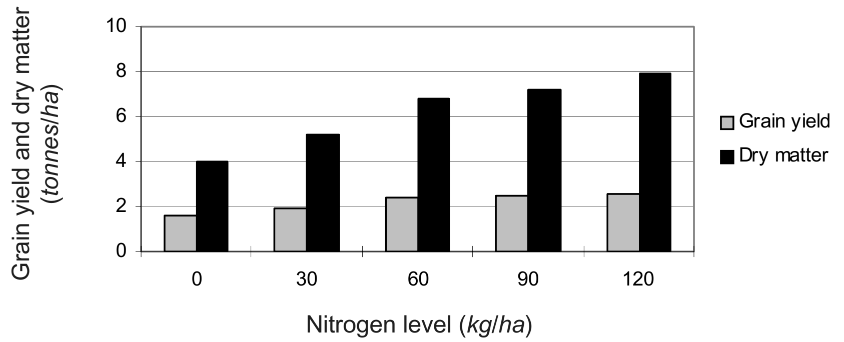
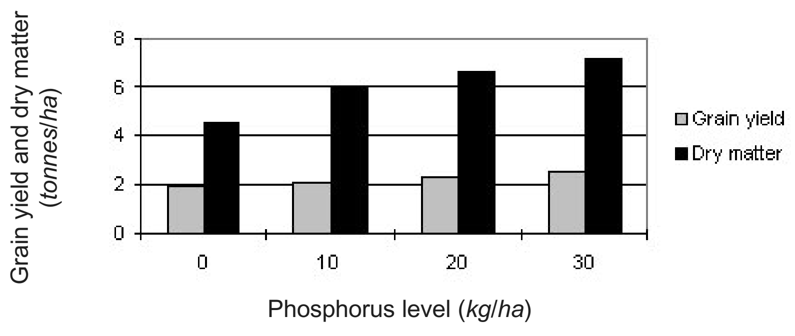


FIGURE 6
Triticale grain yield and straw dry-matter response to phosphorus levels under drought conditions in Morocco



progress achieved by CIMMYT in identifying improved lines with better N use under both low and high inputs. Under the drought conditions of North Africa, the grain and biomass yield response of triticales has shown to be substantially higher with larger increments of nitrogen and phosphorus inputs (Figure 5, Figure 6) (Mergoum, Ryan and Shroyer, 1992). Similarly, data collected over years in different agro-ecological zones of Morocco have shown that triticale outyielded both best wheat (bread and durum) and barley cultivars in semi-arid zones at high elevation and in the Atlantic coastal areas (Mergoum, 1989). In sandy coastal soils, where triticale yielded more than 5 tonnes/ha, neither wheat nor barley exceeded 1 tonne/ha (Mergoum, 1989; Mergoum, Ryan and Shroyer, 1992). Similar results have been reported elsewhere showing the adaptation of triticale to stressed environments, particularly to water stress (Aniol, 2002; Barary *et al.*, 2002).

End-use quality characteristics

Triticales have been selected for better grain type (e.g. grain plumpness and test weight) since the improvement programme was started at CIMMYT in 1964. The most significant improvement for plumper grain was obtained concurrent with the identification of Armadillo and its derivatives. The test weight of the best Armadillo selections in 1970 at Navojoa, Sonora, Mexico, was 73.7 kg/hl compared to 65.8 kg/hl of the best line in 1968 (Zillinsky and Borlaug, 1971). Substantial progress has continued for improved test weight, and some modern triticales can reach 80 kg/hl under favourable environmental conditions.

While the shift in breeding emphasis to complete R genome and 6D(6A) triticale in the 1980s was accompanied by an improvement in test weight, leavened bread-baking quality was negatively affected. Since 1990, due to specific end-use and market requirements, more emphasis has been given to developing triticale for specific end-uses, such as milling and baking purposes, feed grain, dual-purpose forage/grain and grazing types. Low gluten content, poor gluten strength and high levels of alpha-amylase activity caused mainly by pre-harvest sprouting generally result in triticale flour with weak dough that is unsuitable for many bread-making operations. However, there is pre-harvest sprouting tolerance and gluten quality variability in triticale, which allows breeders to select for improved dough quality (Amaya and Peña, 1991; Peña, Mergoum and Pfeiffer, 1998) and therefore bread-making quality.

In general, facultative- and winter-habit triticale produce higher forage biomass than spring types. Therefore, their use for forage (grazing), cut forage, silage, cut forage/grain or hay has been proven through the release of several forage-specific cultivars. In addition, in many countries cereal straw is a major feed source for animals and in some years can have greater value than grain (Benbelkacem, 1991; Mergoum, Ryan and Shroyer, 1992; Ouattar and Ameziane, 1989). Under arid and semi-arid conditions, triticale has been shown consistently to produce higher straw yields than wheat and barley (Mergoum, Ryan and Shroyer, 1992).

Pest and disease resistance

Initially, diseases did not appear to be a serious constraint to triticale production, probably because the areas grown to triticale were not sufficient to cause serious shifts in pathogen virulence. As triticale area expanded, this situation changed, and most wheat and rye diseases now also occur on triticale (Zillinsky, 1985; Singh and Saari, 1991; Mergoum, 1994). Since 1971, CIMMYT has monitored the major diseases affecting triticale around the world. In comparison with wheat, triticale appears to have good resistance to several common wheat diseases and pests including: rusts (*Puccinia* sp.), *Septoria* sp., smuts (*Ustilago* and *Urocystis* sp.), bunts (*Tilletia* sp.), powdery mildew (*Blumeria graminis*), cereal cyst nematode (*Heterodera avenae*) and Hessian fly (*Mayetiola destructor*). It also resists virus diseases, such as barley yellow dwarf, wheat streak mosaic, barley stripe mosaic and brome mosaic (Varughese, Pfeiffer and Peña, 1996a; Skovmand, Fox and Villareal, 1984). However, triticale has relatively greater susceptibility than wheat to diseases such as spot blotch (*Bipolaris sorokiniana*), scab (*Fusarium* sp.) and ergot (*Claviceps purpurea*) and bacterial diseases caused by *Xanthomonas* sp. and *Pseudomonas* sp., which preclude the immediate commercial introduction of triticale in those areas where wheat is otherwise better adapted (e.g. Zambia and parts of Brazil) (Skovmand, Fox and Villareal, 1984).

The reaction of triticale to many diseases meets the expectations of a combined resistance found in the two parental species. The disease and insect resistance reactions of one or the other of the parents is reflected in triticale progeny, or the reaction of triticale is intermediate between that of wheat and rye, as in the case of take-all (*Gaeumannomyces graminis*) and Russian wheat aphid (*Diuraphis noxia*).

Preliminary results on the behaviour of triticale compared with inoculation by several cereal pathogens under greenhouse conditions show that triticale can be as vulnerable as any other cereal to most prevalent diseases. Similar findings on the susceptibility of triticale to certain pathogens, such as yellow rusts (Zillinsky, 1974; Saari, Varughese and Abdalla, 1986), *Septoria* (Zillinsky, 1983; Saari, Varughese and Abdalla, 1986; Skajennikoff and Rapilly, 1985; Eyal and Blum, 1989), *Bipolaris sorokiniana* (Bekele *et al.*, 1985; Skovmand, Fox and Villareal, 1984; Zillinsky, 1983) and *Pyrenophora tritici-repentis* (Martens, Seamen and Atkinson, 1988; Saari, Varughese and Abdalla, 1986; Felicio, Camargo and Leite, 1988), were also reported previously. The virulence of isolates, particularly those of pathogens *Pyrenophora* *tritici-repentis*, *Bipolaris sorokiniana* and *Septoria nodorum*, originating from both bread wheat and triticale, suggests that, probably, the same race can attack both wheat and triticale. Early work had shown that some pathogens, such as leaf rust (*Puccinia triticina*) (Fuentes, 1973; McIntosh and Singer, 1986) and stem rust (*P. graminis* f. sp. *tritici*) (Lopez, Rajaram and de Bauer, 1973), have a wide host range, including triticale and wheat. However, new recombinants from *tritici* and *secali* races for certain pathogens can also be considered (Lopez, Rajaram and de Bauer, 1973; Fuentes, 1973).

CURRENT AND FUTURE CHALLENGES

Future challenges are guided by CIMMYT's mission, which is to help poor farmers by increasing the productivity of resources committed to cereals in developing countries while protecting natural resources (Rajaram *et al.*, 1993). The relatively low adoption of triticale by farmers in several countries is in contrast with encouraging international nursery data, cultivar releases and reports from NARS scientists and on-farm data, which indicate the high production potential of triticale, particularly for small farmers in marginal environments. However, there are several transitory social- and economic-related issues that limit triticale expansion in many countries (Saade, 1995). Improvements in several economic and biological traits are required in order to tailor this crop to fit farmers' needs and market requirements. Following are some challenges that the authors believe will play an essential role in the future of triticale.

Genetic variability

Due to a lack of natural evolution and the relatively 'young' nature of the crop, triticale breeders have been continuously facing challenges associated with generating enough genetic diversity for continued crop improvement. Hence, a strategy for crop enhancement is necessary that emphasizes the maintenance and generation of genetic diversity, while carefully balancing diversity objectives required to ensure long-term progress with the relatively narrower frequency of favourable alleles necessary to achieve short-term breeding goals.

In triticale, the lack of inherent genetic diversity may be overcome by the varied spectrum of potentially introduced diversity. For example, spring and winter wheat and rye gene pools are accessed through direct interspecific (wheat x triticale) and intraspecific (winter triticale x spring triticale) crosses. Octoploid x hexaploid triticale crosses guarantee an influx of cytoplasmic variability. Many modern triticale lines developed from such crosses carry D(A) and D(B) whole chromosome substitutions or chromosome translocations and add valuable traits to triticale. Genetic systems from wheat alien species, e.g. *Aegilops tauschii* (syn. *Triticum tauschii*), are transferred into triticale via wheats carrying alien introgressions.

Furthermore, results from CIMMYT International Triticale Yield Nurseries suggest adaptive advantages of complete triticale carrying a 6D(6A) substitution. The optimal chromosomal constitution of triticale – the make-up of homeologous AA, BB, DD and RR chromosomes or chromosome arms – has yet to be defined, and unique optimal chromosomal configurations for the diverse agro-ecological zones and end-uses are likely to emerge. Unique combinations can be constructed in hybrid triticale.

Modification of phasic development for specific adaptation

The development of populations with specific traits facilitates the combination of desirable traits from different unadapted genotypes with adapted germplasm. Recently, more emphasis has been directed towards improving certain triticale agronomic traits, including grainfilling duration and rate, earliness and tillering capacity, but quality parameters have also been addressed, such as test weight, protein content and gluten strength enhancement (Boros, 2002).

Triticale in general requires a longer grainfill period than wheat, although the number of days to flowering can be similar. In arid and semi-arid zones, where there is potential for triticale production to expand, terminal drought is frequent. With its slower maturity, triticale production may be limited under such climatic conditions by vulnerability to terminal stress and late/early frost situations with drastic effects on grain yield. Therefore, future research efforts should focus on shortening the grainfill duration and increasing the grainfill rate.

Biotic stresses

Although triticale has shown good resistance to most prevalent diseases and insects in most cereal-growing areas, with the spread of this crop and the race specialization of pests, triticale has become vulnerable to certain diseases or insects. During dry years in North Africa (1992-1995), several triticale genotypes became susceptible to a new emerging biotype of Hessian fly and Russian wheat aphid. Selection for resistance to these pests is now included in the CIMMYT programme.

Reports from Ecuador and the highlands of Mexico (Toluca) (CIMMYT, 1996) showed that more than 20 percent of CIMMYT triticale germplasm was susceptible to a new race of stripe rust (*Puccinia striiformis*) (Plate 3). The Toluca strain at least is suspected to have overcome *Yr9* in wheat. Consequently, efforts now concentrate on the development of different sources of resistance to stripe rust in CIMMYT germplasm. Similarly, in Australia in 1984/85, two new races of wheat stem rust (*Puccinia graminis tritici*), races 34-2,12 and 34-2,12,13, arose that proved virulent on 90 percent of CIMMYT introductions and on nine of the ten current Australian triticale cultivars. Locally produced germplasm and the few resistant adapted CIMMYT introductions rapidly replaced susceptible materials in Australian breeding programmes, and a testing service for resistance to race 34-2,12,13 was established (K.V. Cooper, personal communication).

Abiotic stresses

Breeding for the abiotic stresses of marginal lands (acid, sandy or alkaline soils), trace element deficiencies (copper, manganese and zinc), or trace element toxicity (high boron), and the different types of moisture stresses will still constitute a major effort in spring and winter/facultative triticale improvement at CIMMYT. This can be achieved by exploiting key locations during selection, screening and yield testing and through shuttle-breeding involving NARSs (e.g. Brazil for acid soils and sprouting and Morocco for terminal drought and sandy soils).

End-use quality requirements

Animal feed and forage

The advantage of triticale in farming systems has been primarily in animal feeding. To date, most of the triticale production is used either as animal feed grain, forage, or both (Belaid, 1994; Saade, 1995). Facultative- and winter-habit triticales, in general, produce higher forage biomass than spring types; therefore, they are more suitable for forage grazing, cut forage, silage, cut forage/grain or hay. Forage and forage/grain dual-purpose triticales are a new area of breeding and research at CIMMYT. Such triticales may complement crop and livestock enterprises in developing countries. In contrast to grain triticales, the requirements in terms of growth habit are highly environmental and management specific, particularly for dual-purpose and multiple-forage harvest situations (Plate 4). A new international triticale nursery consisting of facultative and winter grain and forage triticale advanced lines (FWTRITICALE) has been created to complement the existing international nurseries. Several advanced lines have already been selected and released from this nursery. In the northern states of Mexico, released winter triticales AN 31 and AN 34 and promising lines TCL 38, TCL 39 and TCL 78 from the joint programme of the Universidad Autónoma Agraria Antonio Narro in Saltillo, Coahuila, Mexico, and CIMMYT outperformed substantially the forage production of other crops, such as barley, ryegrass and oats (Figure 7).

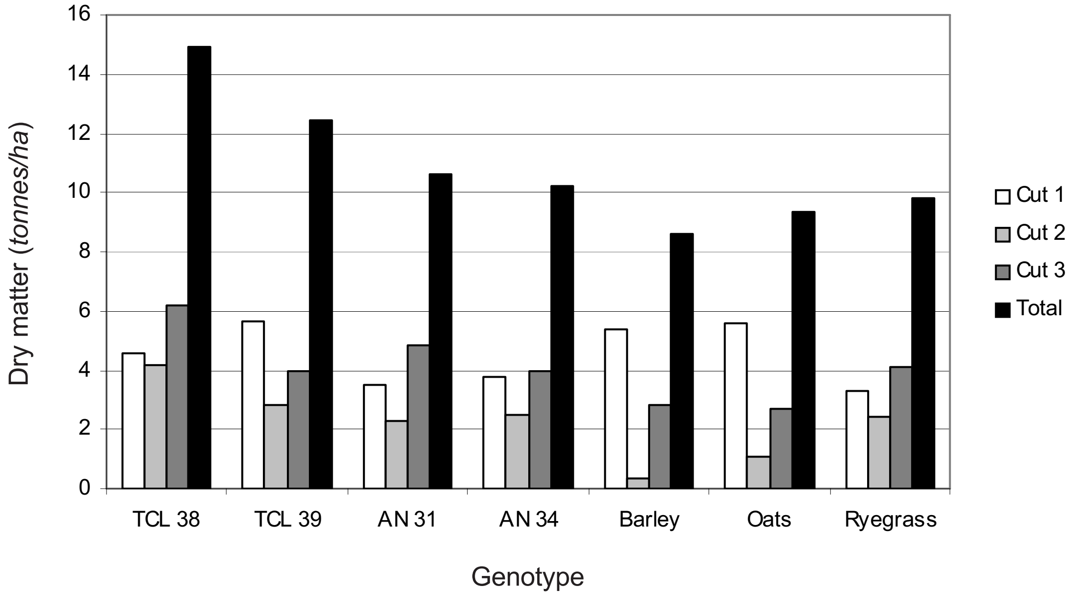
As animal feed, triticale has clear advantages. Its amino acid composition fits the nutritional requirements of monogastrics and poultry very well (Belaid, 1994; Pfeiffer, 1994; Saade, 1995; Varughese, Pfeiffer and Peña, 1996b). Studies in Algeria and Tunisia have shown that triticale can substitute for maize in poultry feed rations (Belaid, 1994; Saade, 1995). Chemical analysis of promising triticale lines should become a regular technique in cultivar screening in the future at CIMMYT in order to identify genotypes with a desirable nutritional profile. Research should focus on the characterization of the nutritional value of triticale genotypes and the selection of new cultivars with improved biological value for poultry, e.g. with high crude protein content and metabolized energy.

In many countries, cereal straw is a major feed source for animals and can have higher value than grain, especially in dry years (Benbelkacem, 1991; Mergoum, Ryan and Shroyer, 1992; Ouattar and Ameziane, 1989). Triticale usually surpasses wheat and barley in straw production, particularly in arid and semi-arid zones (Mergoum, Ryan and Shroyer, 1992). Research characterizing straw quality requirements and potential is required.

Human consumption

Triticale grain and flour is generally a good source of vitamins and mineral nutrients (Lorenz, Reuter and Sizer, 1974). In addition, protein concentration is similar to wheat, while lysine levels can be enhanced (Villegas, McDonald and Gilles, 1970). Thus, selection for enhanced nutritive value will impact those communities where cereal-based diets predominate, in particular with women and children. Similarly, new methodologies, particularly in plant transformation using molecular biology techniques, which have been shown to be more successful with triticale versus other cereals, could be investigated as a promising tool to improve the nutritive quality of triticale.

FIGURE 7
Dry-matter forage production (total and per cut) of winter triticale cultivars AN 31 and AN 34 and lines TCL 38 and TCL 39 compared to barley, oats and ryegrass in northern Mexico



Milling and baking

Recent reports indicate that triticale is widely used as feed grain and/or forage, while its utilization for human consumption is still limited. Until recently, breeders have concentrated their efforts on improving triticale agronomic characters and disease resistance, while less attention has been given to the improvement of traits associated with grain colour and bread-making quality (Peña, 1994). However, today's triticale can substitute for soft wheat to make various soft-wheat type products, such as cookies and biscuits.

Genetic gains for quality traits based on existing genetic variability and heritability estimates (Pfeiffer, 1994) indicate that progress can be expected. High-yielding, complete triticale germplasm is now available with acceptable loaf volumes (Plate 5). However, relying on the existing variability for baking quality parameters may not solve the inherent limitations in the bread-making quality of triticale. Current baking quality improvement strategies focus on the accumulation of favourable non-enzymatic endosperm proteins. In hexaploid wheat, the genes for non-enzymatic storage proteins are located on the chromosomes of group 1 (glutenins and gliadins) and group 6 (gliadins). Among those, the high molecular weight (HMW) subunits of glutenin coded by presumably homologous gene loci on the long arm of chromosome 1A, 1B and 1D are closely associated with bread-making quality (Pfeiffer *et al.*, 1996). Crosses have revealed at least 21 allelic variants at glutenin subunit loci *Glu-A1*, *Glu-B1* and *Glu-D1*. The relative importance of the glutenin subunit loci *Glu-A1*, *Glu-B1* and *Glu-D1* approximates a ratio of 20:30:50 (Pfeiffer *et al.*, 1996).

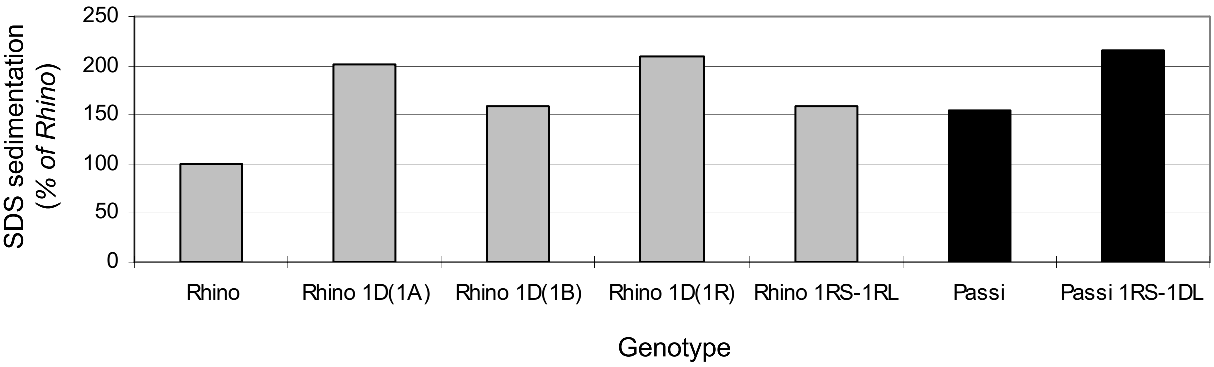
Hexaploid triticales not only lack the *Glu-D1* genes for quality, but complete triticales carry the major endosperm secalin proteins *Sec-1*, *Sec-2* and *Sec-3* on the rye genome, which may negatively affect baking quality (substituted triticales carry *Sec-1* and *Sec-3*). The favourable HMW loci on *Glu-A1*, *Glu-B1* and *Glu-D1* have been transferred to triticale and are being combined in targetted crosses, aiming to impact significantly gluten strength and bread-making quality in triticale. The effect of transferring *Glu-D1* HMW glutenin subunits into triticale is shown in Figure 8.

High alpha-amylase activity is a common defect of triticale grain (Trethowan, Peña and Pfeiffer, 1994). High levels of enzymatic activity have a detrimental effect on the functional properties of bread-making dough. Selection for reduced enzymatic activity and tolerance to pre-harvest sprouting is necessary to improve utility and marketing stability.

Grain characteristics

Dark colour and shrivelled grains still remain a major handicap for triticale expansion and use in many

FIGURE 8
Effect of D-genome chromosome substitutions or translocations on quality parameters of spring CIMMYT triticales Rhino and Passi



Source: Varughese, Pfeiffer and Peña, 1996b.

countries, particularly when the grain is ground to obtain wholemeal flour to produce baking products (for example, flat breads in North Africa and India). Therefore, since the 1995/96 crop cycle, substantial emphasis has been given to these traits, and an intensive crossing programme was launched to incorporate these traits into the best performing triticale genotypes. Advanced white grain triticale lines (F_5, F_6 and F_7), selected based on white colour, were included for the first time in yield test trials at Ciudad Obregón in 1997/98. Best performing lines with yield similar to traditional dark grain were distributed to NARSs through the International Triticale Screening Nursery and the International Triticale Yield Nursery. However, more selection cycles might be needed to combine the white grain colour trait into most best quality lines that exist in CIMMYT germplasm in order to meet quality standards for human uses of triticale.

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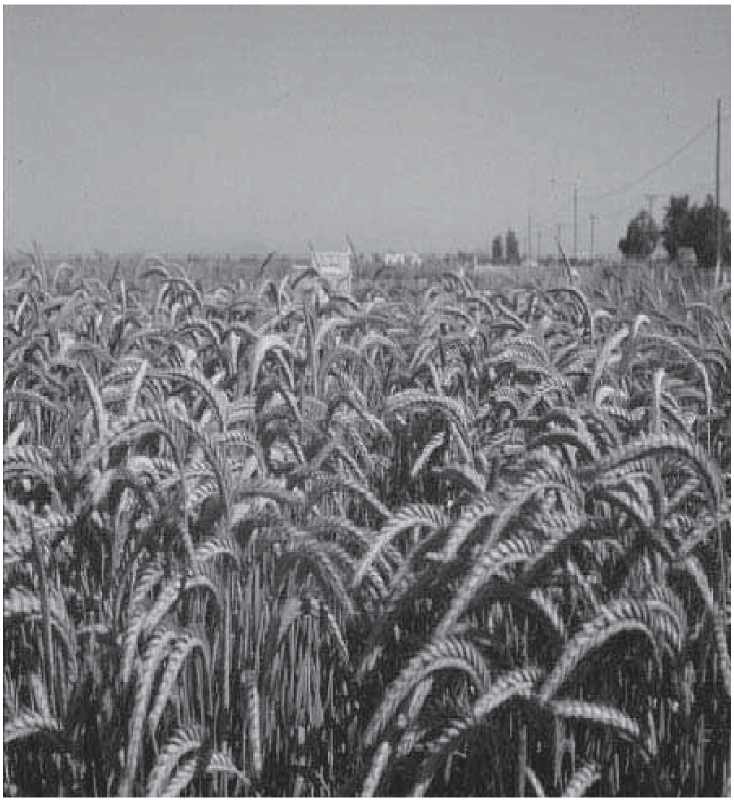
PLATE 1
Triticale, still a ‘promising’ crop with great potential, yet to be fully exploited
M. Mergoum



a - awnless triticale at early-milk stage suitable for forage or hay use in Morocco

b - early-maturing triticale for grain production in Morocco

PLATE 2
CIMMYT triticale Juanillo 'S' showing tolerance to drought in a barley nursery in a very dry environment at Sidi Laydi, Settat, Morocco
M. Mergoum

PLATE 3
*Resistant versus susceptible triticale lines to the new stripe rust (*Puccinia striiformis*) race at Toluca, Mexico*
M. Mergoum

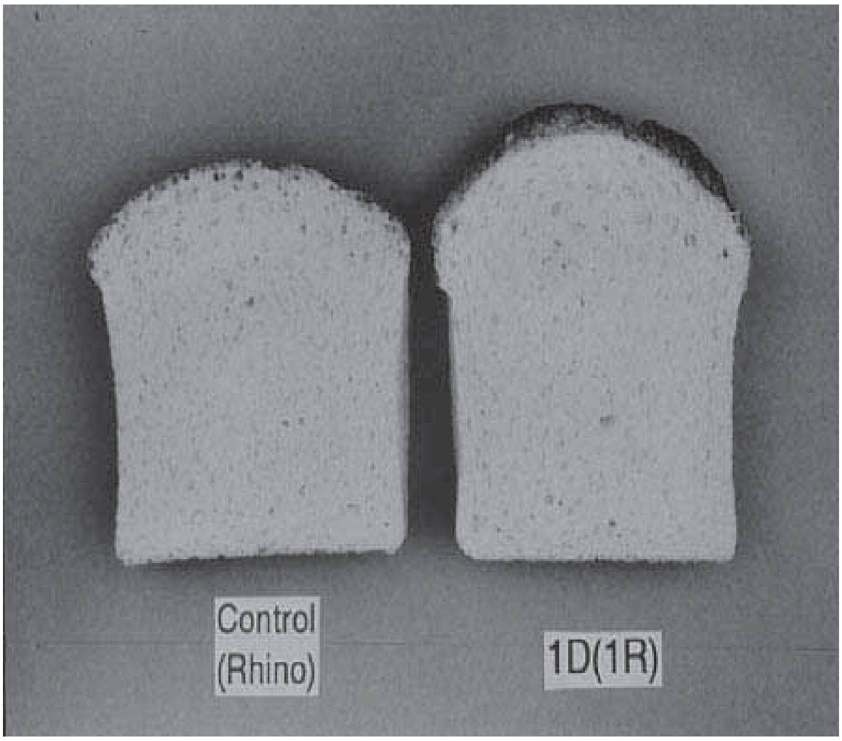
PLATE 4
High forage production for silage using triticale in northern Mexico
A.J. Lozano del Río

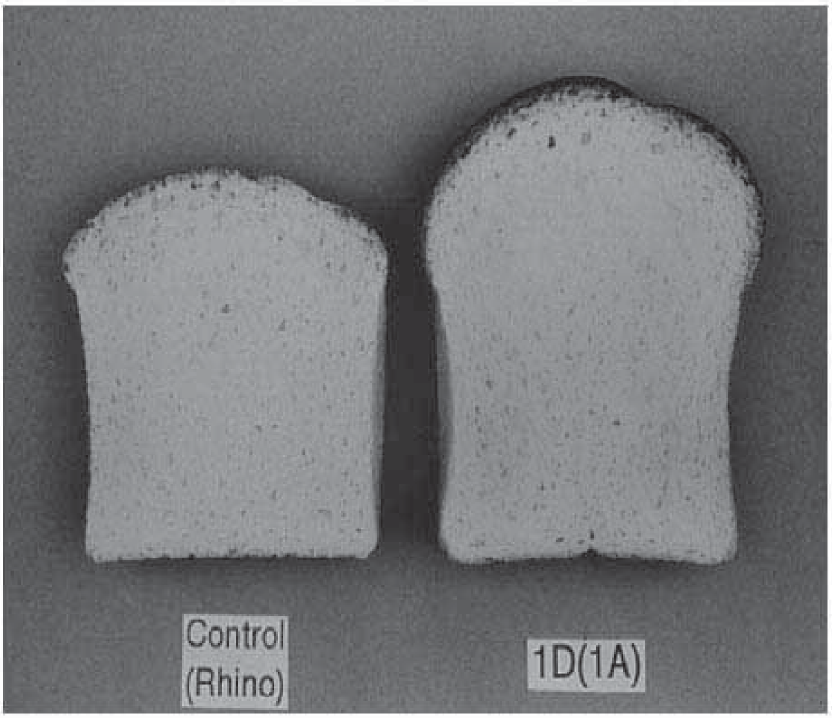
PLATE 5

Bread loaves showing quality variability in Rhino spring triticale

R.J. Peña

a - 1D-chromosome substitution for 1R chromosome compared to complete Rhino





b - 1D-chromosome substitution for 1A chromosome compared to complete Rhino

Triticale production and management

D.F. Salmon, M. Mergoum, H. Gómez Macpherson

Triticale as a species has not had the opportunity to evolve over the last millennium in a fashion similar to its parental species wheat and rye. It was not until the latter part of the nineteenth century that it was first described as a robust combination between wheat and rye. Early attempts at hybridization between the two species resulted in sterile offspring. It was not until the 1930s that a method involving the chemical colchicine was discovered that resulted in chromosome doubling and subsequent fertility.

The initial interest in triticale was the potential of this new crop to combine the genetic attributes of both wheat and rye. In other words, a human food and animal feed crop that could be grown on marginal land under limited soil fertility and moisture.

In the early stages, work concentrated on two types of triticale, the hexaploid combining the A, B (durum and turgidum) and R (rye) genomes and the octoploid combining the A, B, D (bread wheat) and R genomes. The fact that the octoploid produced very large spikes and embryo rescue was not required in it resulted in much of the work during the first half of the twentieth century being focussed on octoploids. However, the relatively poor seed development in the octoploid versus the hexaploid, as well as instability, resulted in many programmes converting to breeding hexaploids in both the winter and spring versions of triticale. In more recent years, work has been conducted on tetraploid triticale, which combines the R genome of rye with the A and/or B genomes from wheat ancestors.

One of the most significant breakthroughs in triticale during the last part of the twentieth century was the development of the Armadillo type of triticale at the International Maize and Wheat Improvement Center (CIMMYT) in Mexico during the 1970s, which greatly enhanced the levels of self-fertility in the crop. A second major development was seed plumpness. Plump-seeded triticale types from CIMMYT greatly advanced the potential for triticale in human food and animal feed. A third factor that has significantly impacted winter triticale is the development of excellent agronomic types by winter breeding programmes in Poland, thereby allowing triticale to expand into very high-yielding areas of Europe where lodging of tall winter triticale was a problem and providing valuable germplasm for agronomic improvement in areas where winter hardiness tended to be coupled with poor agronomic type (Northern Europe and North America). These factors have had a major impact on the development and utilization of triticale (see chapter "The history and evolution of triticale").

PRODUCTION

Triticale worldwide

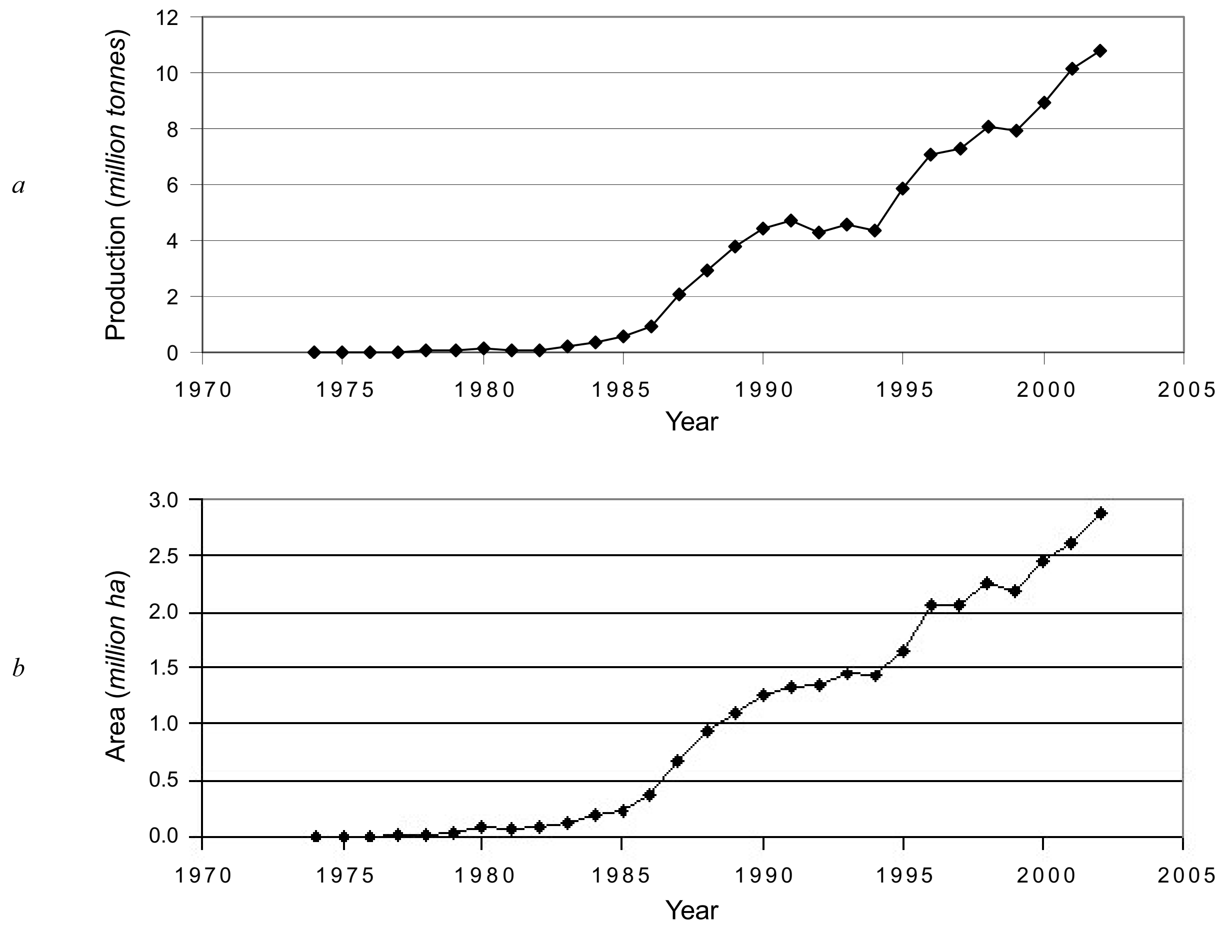
The evolution of triticale as a commercial crop was slow until the mid-1980s (Figure 1). Since then triticale production has increased at an average rate of 150 000 tonnes/year (an approximate 18 percent increase per year), reaching nearly 11 million tonnes in 2002 (FAO, 2003). In this same year, sorghum, oat, millet and rye world production was approximately 54, 25, 23 and 21 million tonnes, respectively. However, in contrast to triticale, the world production of these cereals has decreased in the last fifteen years, and the trend seems to be continuing.

The steady increase in triticale production has been mostly due to an increase in the area planted, which has increased at an average rate of 578 000 ha/year (23.6 percent/year) since the mid-1980s (Figure 1). At present, the total area planted to triticale worldwide is nearly 3 million ha (FAO, 2003).

Triticale yield has also increased since the mid-1980s, particularly when shorter, spring-type varieties became commercially available allowing an escalation in the use of fertilizers without increasing the risk of lodging. The new varieties had higher harvest index and yield (see chapter "Triticale crop improvement: the CIMMYT programme"). Additionally, in the mid-1980s, highly productive winter triticale varieties were developed in Poland, and the crop extended into favourable environments in Northern Europe.

At the world level, the average annual increase in triticale production per hectare since 1985 has been nearly 100 kg/ha/year, which is remarkable compared to 45, 39, 28 and 21 kg/ha/year for maize, rice, wheat and barley, respectively, during the same period. In 2002, the highest country average yields were 6.8, 6.3 and 5.5 tonnes/ha in Switzerland, Belgium and France,

FIGURE 1
Worldwide triticale total production (a) and area planted (b), 1974-2002



Source: FAO, 2003.

respectively (FAO, 2003). In contrast, production per hectare was approximately 1 tonne/ha in rainfed environments where inputs are very low.

Although triticale is grown in many countries of the world, the major producers are in Europe. In 2002, approximately 88 percent of triticale was produced in Europe, 9 percent in Asia and 3 percent in Oceania (FAO, 2003). The major European producers were Germany, Poland and France, whereas most of the Asian production was in China. In this same year, 75 percent of the total hectares planted in the world to triticale was in Europe, 16 percent in Asia and 9 percent in Oceania, mostly in Australia. Although used primarily as a forage crop, triticale has been increasing dramatically in the Americas.

The most significant increases in production have been in central and eastern European countries. Poland, for example, had winter triticale production levels that exceeded 800 000 ha during 2001 compared to 20 000 ha in 1985 (FAO, 2003). In the same year, China, Germany, Poland and France produced nearly 80 percent of the world triticale, and most of it was consumed internally as feed (Table 1). At present, trade in triticale is not a significant factor. Germany is the main exporting country (164 398 tonnes in 2001), followed by Hungary. In the case of triticale imports, most of it was carried out by European countries (a total of 152 500 tonnes in 2001), the Netherlands being the main importing country.

Production zones

Triticale closely overlaps the areas of adaptation common to the extremes of its wheat and rye parents. As a consequence, environment determines which type of triticale is the most suitable for production. Currently, there are three categories of triticale: (i) spring types that do not require a cold treatment/vernalization to move from the vegetative to reproductive phase; (ii) intermediate or facultative types that have some cold treatment requirements but will go into the reproductive phase

TABLE 1
Triticale statistics of main triticale-producing countries, 2001

Statistic	China	France	Germany	Poland
Production (*tonnes*)	640 380	1 123 196	3 418 892	2 697 862
In relation to world (*%*)	6	11	34	27
Area (*ha*)	202 000	240 776	533 492	838 274
Yield (*tonnes/ha*)	3.17	4.66	6.41	3.22
Imports (*tonnes*)	2	8 937	2 099	579
Exports (*tonnes*)	25 526	8 611	164 398	381
Stock (*tonnes*)	-	-	-170 593	-353 060
Feed (*tonnes*)	200 000	1 083 522	2 911 000	1 950 000
Seed (*tonnes*)	67 000	40 000	90 000	213 000
Waste (*tonnes*)	26 000	-	68 000	150 000
Processed (*tonnes*)	325 000	-	-	12 000
Other utilizations (*tonnes*)	-	-	17 000	20 000

Source: FAO, 2003.

without a cold treatment; and (iii) winter types that require a cold treatment after germination to go into the reproductive phase.

Potential production areas

Potential production areas for triticale can in part be defined in a similar fashion to wheat as described by Fischer (1981). In general, spring triticale can be grown for grain production in most environments that have a sufficiently long growing season and adequate moisture either from natural rainfall or from irrigation, as well as in areas where winter conditions are not severe. As a consequence, spring triticale may be most suited to:

- High-latitude (45° or higher) areas, such as the northern Great Plains of North America, the Russian Federation, republics of the former Soviet Union and northern China, where spring triticale is sown in the early spring.
- Lower to middle latitude (between 45° and 30°) areas, such as the Mediterranean, the southern part of South America, Pakistan, India and parts of China, where the winters are sufficiently mild and adequate moisture is available either through natural sources or irrigation; spring triticale is sown in the winter.
- Low-latitude (less than 30°N or 30°S) areas, such as Kenya, the United Republic of Tanzania, Zambia, Ethiopia and central and northern South America, where crops are grown under rainfed conditions and sown in the early part of the spring and summer on upland (greater than 1 500 m) production areas.

The potential areas for production of winter types tend to overlap to a significant degree with spring triticale. The intermediate or facultative types may be grown for grain as well as for a grazing and high-yielding forage crop in many areas that do not have strong vernalizing conditions and do not require cultivars with high levels of hardiness. The winter types require a significant period of time (four to eight weeks) of low temperatures (above freezing but below 9°C) to cover the vernalization requirements as well as to ensure adequate development of cold tolerance. Winter triticale is generally suited to:

- Planting in the autumn in high-latitude areas where conditions are cool enough to fulfil vernalization and hardening requirements and where there is sufficient snow cover to ensure winter survival, such as Northern Europe, the northern Great Plains and eastern North America, parts of the Russian Federation and China.
- Planting in the autumn in middle- to high-latitude areas where conditions are cool enough to fulfil vernalization requirements but without extreme requirements for winter hardiness, such as Eastern and Western Europe, the United States of America, central China, as well as parts of Turkey and the Islamic Republic of Iran.

Photoperiod

Triticale has a wide area of adaptation around the world. Although general climate and latitude have an important impact on the decision whether to grow a spring or a winter type, photoperiod can be a concern. During the early stages of triticale breeding, spring types used in northern latitudes tended to be daylight sensitive. In this case, they required in excess of 12 hours of light to initiate change from the vegetative state. In a similar fashion, the obligate winter types required not only the vernalization period but also long days. The development of daylight-insensitive (CIMMYT) types has greatly eliminated this problem for the production of triticale at lower latitudes where day-lengths are short (Krull *et al.*, 1968).

Much of the spring germplasm utilized in current programmes in high-latitude countries has a strong CIMMYT background, and many of the varieties produced are daylight-insensitive types. On the other hand, much of the winter germplasm may still have a significant degree of daylight sensitivity. Daylight sensitivity in spring types may be an advantage (A. Hede, personal communication) in climates, such as some of the former Soviet Union republics (Kazakhstan) and parts of northern China, that are hot and dry in the summer and have cold winters without adequate snow cover to support winter types. Delay in heading while photoperiod requirements are being fulfilled may result in higher production than in the day-neutral types. However this has yet to be confirmed.

CULTIVATION

Adaptation zones

Triticale performs well under rainfed conditions throughout the world and excels when produced under good soil fertility and irrigation. Although triticale responds very similarly to wheat grown under a wide range of environments, it is in general superior under stress conditions. Many triticale cultivars carry tolerance to acid soils (Baier, de Sousa and Wietholter, 1998) and high aluminium toxicity (Butnaru, Moldovan and Nicolae, 1998) and may have tolerance to other problems, such as soils high in manganese, which is typical of some soils in Australia (Zhang, Jessop and Alter, 1998). The acid tolerance and aluminium tolerance are more similar to its rye ancestors.

In areas where abiotic stresses, such as drought, extreme temperatures, extreme pH levels, salinity and trace elements deficiency or toxicity, are prevalent, triticale has consistently shown to be very competitive compared to the other cultivated cereal crops. Previous work in the dry regions of North Africa with low inputs (Belaid, 1994; Mergoum, Ryan and Shroyer, 1992; Mergoum, 1994; Ouattar and Ameziane, 1989; Saade, 1995; Varughese, Pfeiffer and Peña, 1996) has clearly demonstrated that triticale offers additional end-uses and alternatives for humans and animals, such as grazing and straw. In high-input areas (irrigated and high-rainfall regions), triticale can be used as forage or for dual purposes.

Triticale performance under acid soils (in Brazil for example) has demonstrated excellent tolerance to low pH levels. For this reason, triticale has been grown on a substantial area (more than 120 000 ha) in Brazil in the southern regions of Rio Grande do Sul, Paraná and Santa Catarina (see chapter "Triticale crop improvement: the CIMMYT programme").

Crop establishment

As with all cereals, triticale should be planted into a firm seedbed and placed near moisture. This can pose a problem when planting winter cereals. Although triticale has a very large seed and has a very robust embryo, in cooler climates it has been observed in the early stages of development to be slow growing compared to other cereal species, such as barley and wheat. This may be due to the early development of a massive root system versus early top growth, which is in contrast to the general perception that triticale as a species is a very robust and competitive crop during its growth in many of its adapted production zones. Triticale seed size generally is larger than that of commonly grown wheat varieties (Plate 1). Consequently, spring triticale can be seeded more deeply than other small cereals and therefore benefit from stored moisture in the soil, which allows better crop establishment early in the season, particularly in drought-prone areas. Seeding equipment needs to be set to account for a seed that may be 10 to 20 percent larger than wheat.

Seed placement during the planting process is very important when dealing with winter triticale cultivars grown in areas that have extremely severe conditions during the winters at high latitudes as well as at high elevations in the middle latitudes. Work conducted in the northern Great Plains of North America has indicated that winter triticale varieties equal and in many cases exceed the winter hardiness of the best winter wheats if planted early during the autumn and if planted shallow (no more than 2.45 cm deep). It appears that winter triticale varieties take longer to develop their maximum cold tolerance, and deep planting increases the time to emergence and results in a less robust crown, a factor extremely important in winter survival under severe winter conditions. Winter survival under these conditions is greatly enhanced by using snow trapping (Bauer and Black, 1990), planting practices with minimum soil disturbance and trash cover (Plate 2).

The use of minimum soil disturbance has advantages for the production of both spring and winter triticale types. In Mexico, Sayre *et al.* (1998) noted a slight yield advantage for triticales grown under zero-tillage. Use of minimum soil disturbance techniques such as zero-tillage maintains straw on the production fields, reduces erosion, increases soil microbe activity, improves soil tilth, maintains soil fertility and reduces the usage of expensive agricultural fuels. However, in areas with severe cereal diseases, where pathogens can be carried over on cereal crop residues, good rotation practices with non-host species are essential.

Fertilization, weed control and pest control

Triticale has a very extensive root system and can mine the soil more efficiently in conditions where fertility is poor. When any new crop is introduced into a production area there usually is only limited information on fertilizer usage. Fertility work is very specific to climatic and soil zones. In general, triticale will respond favourably to cultural practices commonly used for the parental species wheat. However, work conducted at CIMMYT in Mexico (Sayre, Pfeiffer and Mergoum, 1996) demonstrated clearly the substantial genetic progress achieved by CIMMYT in identifying improved lines with better nitrogen use under both low and high inputs. Under drought conditions in northern Morocco, the grain and biomass yield response of triticales have shown to be substantially higher with larger increments of nitrogen and phosphorus inputs (Mergoum, Ryan and Shroyer, 1992).

Good soil fertility along with vigorous germination and fast emergence may be one of the most efficient ways to reduce weeds through competition (Schoofs and Entz, 2000). A vigorously growing crop usually is relatively weed-free. Triticale is a relatively new crop in many parts of the world and as a consequence may not have many, if any, herbicides or pesticides recommended for it. In most cases, the herbicides and pesticides that work on wheat and rye will work on triticale. However, Haesaert, Deryche and Latre (1998) have indicated that triticale may be less tolerant to some herbicide cocktails than wheat. Newer herbicides as well as pesticides are now being released with recommendation for use on triticale in many parts of the world.

Harvest and storage

Seed size may also be of concern when harvest is occurring. Triticale varieties generally have a large seed and a large embryo with an elongated beak compared to bread wheat. Caution must be taken to ensure that any mechanical harvesters, such as modern combines, are appropriately set so that there is no damage to the embryo. Embryo damage and seed cracking can have a significant impact on seed viability during storage. This can be a problem since many triticale varieties are hard to thresh compared to wheat and rye. Some of the reduced-awn varieties, such as the winter triticale Bobcat, carry the wheat rachis (R. Metzger, personal communication) and are easy to thresh.

In triticale without the wheat rachis, threshing frequently results in incomplete seed and chaff removal from the spike, and breakage may occur at the rachis nodes. In the wheat rachis types, breakage does not occur. Improvements in threshing will be an excellent improvement where mechanical threshing equipment is not readily available or economically feasible.

Triticale has a very soft-textured kernel and may be subject to damage from insect infestation during the storage process. Triticale should be stored in a dry, well-ventilated area to reduce potential damage from moisture. Preferred harvest moisture to reduce damage due to heating caused by moulding is 14 percent or less.

END-USES IN AN INTEGRATED CROP PRODUCTION SYSTEM

Livestock feed

Chapters “Food uses of triticale” and “Triticale as animal feed” address the uses of triticale products in detail. However, it is very difficult to discuss production without referring to utilization since production and end-use are an integrated process. Production of triticale allows for the development of diversified rotations, which may reduce weed and disease problems and improve soil husbandry while ensuring a stable, high-quality source of food and feed. As a consequence, it is important to emphasize a few examples where triticale has contributed substantially in feed or forage.

To date, the most common usage of triticale grain as a feedstock has been in poultry and hogs. Work carried out in Poland by Boros (1998) indicated that no negative effects occurred in broiler chickens when being fed either hexaploid or octoploid types of winter triticale. With the exception of the tetraploid type, triticale was similar to wheat and superior to rye as a major ingredient in broiler feed rations. Similar results have been reported in studies involving turkeys and waterfowl.

Other studies conducted on feeding hogs identify triticale as a good source of feedstock with an excellent balance of available amino acids for blended and supplemented feed rations. In particular, work conducted by Jaikaran *et al.* (1998) on spring triticale and Myer (1998, 2002) on winter triticale demonstrated the value of the crop in hog diets. The work of Jaikaran *et al.* consisted of comparisons with hulless barley and maize versus triticale. In this circumstance, triticale performed equally well under all stages of development of the hog as well as in factors involved in determining carcass quality and cooking parameters. Myer's work demonstrated that triticale was very acceptable even in diets fed to very early-weaned hogs, a situation where the hog's digestive system is newly developed so any dietary deficiencies have a major impact on growth.

Triticale is also being used as a source of feed for ruminant species, such as cattle, sheep and goats. The lower levels of gluten and of beta-glucans put triticale in a favourable position for feeding ruminants. The performance of dairy animals as well as meat animals fed triticale is very similar to those fed maize or barley. The high energy content of triticale and the lower tendency to acidify the gut of a ruminant are major factors in good health and long-term production.

Livestock fodder

The use of triticale as a grazing crop (Plate 3) to supplement native pasture, as a silage crop, as a conserved hay crop and as green chop is rapidly increasing. Triticale is used as an important source of fodder in most countries in which it is grown. Recently, triticale areas grown for grazing, forage, silage, hay and dual purposes have increased substantially. Many triticale varieties with different growth habits and agronomic traits aimed at forage production have been developed around the world. Most of these triticale cultivars are awned. However, awnless cultivars have recently been released, which will further increase triticale promotion as a forage crop (Gibson, 2002).

In North America, the use of cereals, in particular winter types, as a grazing crop for livestock is a very common practice. In areas where the winter is mild and the plants continue to grow well into the winter, winter triticale planted in the autumn is a valuable, high-quality source of fodder during the winter. In colder regions, winter triticale, which is seeded in the early spring and remains vegetative, provides very inexpensive grazing well into the late autumn and early winter (Baron *et al.*, 1993). Similar work has been carried out using spring triticale grown during the winter months in Australia and other countries including parts of southern Africa and the Mediterranean and Mexico (Lozano *et al.*, 1998; Lozano del Río *et al.*, 2002). Schoofs and Entz (2000) found that grazing systems involving triticale had an equal effect on weed control for some common weed species as the use of a herbicide.

The most extensive work on triticale, both winter and spring, has been the production of whole-plant silage, dried hay or green chop, which is harvested and fed directly to livestock. In general, triticale produces yields equal to if not superior to other small-grain cereals (excluding maize), such as barley and oat, that have traditionally been used for this purpose. As indicated by Khorasani *et al.* (1997) and Benbelkacem (2002), the quality of forage from spring triticale is quite similar to barley. Early harvest as green chop, dried hay or silage may remove weed species prior to seed production, reducing the weed population in future crops. In climates where early seeding and snow trapping are required for the production of winter cereals, stubble from a silage crop is of considerable value.

Human food

Although the original intention for the development of triticale was production of human food, and the nutritional content certainly indicates high quality, this has not been a major use of the crop. Triticale has been noted for many years as an excellent product for making chapatti tortillas and many forms of leavened bread. The major problem appears to be changing traditions and the need to improve baking quality to a level more similar to wheat. Current breeding programmes in many parts of the world are seriously working on this problem, and gradual improvements are occurring (Peña, Mergoum and Pfeiffer, 1998). It is apparent that the next major breakthrough in triticale breeding, production and utilization will be its development as a human food.

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PLATE 1
Comparison of triticale and common wheat seed
D.F. Salmon

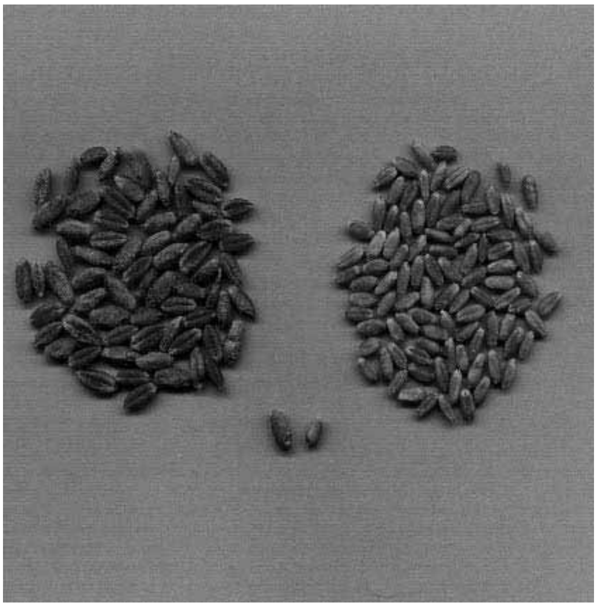

PLATE 2
Winter cereal planted in a minimum-tillage system
D.F. Salmon

PLATE 3
Plains bison grazing on a forage blend that includes triticale
D.F. Salmon

Food uses of triticale

R.J. Peña

Rapid increases in world population demand concomitant increases in food production, particularly of cereal grains, the main source of nutrients for both humans and animals. However, further increases in cereal production must occur while preserving the environment and natural resources. Therefore, production increases must come mainly from enhancing the yield potential of new crops and not from expanding the global cultivated area. Triticale (X *Triticosecale* Wittmack), the product of wheat and rye hybridization, has demonstrated high yield potential even under marginal growing conditions and could be a very attractive alternative for raising cereal production globally. Unfortunately, recent estimates (FAO, 2003) indicate that the area sown to triticale worldwide is approximately 3 million ha, slightly higher than a decade ago. Despite the high productivity of triticale, global production is increasing slowly, and the crop has not yet become well established in local or world markets. The main reason for the lower-than-expected production is that triticale, a good source of protein and energy (Hill, 1991), is used mainly for animal feed but very little for human consumption.

Triticale could become a major crop if, in addition to its use as a feed grain, it were cultivated on a large commercial scale for human consumption. This chapter presents an overview of the potential food uses of triticale and of the grain and non-grain factors associated with utilizing triticale as a food grain. The aim is to stimulate scientists and other professionals to address issues that may help increase triticale production significantly, thereby contributing to raise the global food supply.

FOOD-PROCESSING CHARACTERISTICS OF TRITICALE

The physical characteristics and proximate chemical composition of triticale grain are in general intermediate between its two parent species (Table 1). Triticale's properties for milling and baking, the two main uses of its parent species, have been examined widely. Its potential utilization in malting and brewing has also been studied. Triticale characteristics related to milling, baking and malting are described in this section.

Grain milling

Triticale can be milled into flour using standard wheat or rye flour-milling procedures (Kolkunova *et al.*, 1983; Weipert, 1986). However, the wheat milling process is more suitable for obtaining maximum triticale flour extraction rates, mainly because rye flour milling precludes the use of smooth rolls (smooth rolls tend to flake rye middlings due to their high pentosan content) thus reducing flour extraction rates. Early triticale lines tended to produce low flour yields due to long grains with a deep crease and incomplete plumpness, which made it difficult to obtain high extraction rates of low-ash flours. More recent triticales possessing improved grain shape and plumpness have flour yields equal or closer to those of wheat (Amaya, Peña and Varughese, 1986; Macri, Balance and Larter, 1986a; Ullah, Bajwa and Anjum, 1986; Saxena *et al*., 1992). At low ash content, semi-hard and soft triticales show higher flour extraction rates than do hard triticales, which in this sense resemble durum wheat more than bread wheat (Amaya, Peña and Varughese, 1986; Saxena *et al*., 1992).

One way to improve the milling performance of triticale is to mill wheat-triticale grain blends, as suggested by Peña and Amaya (1992). These authors found that blending wheat and triticale grains in a 75:25 ratio prior to milling produces flour yields equal to those of wheat milled alone (Table 2). Although blending wheat and triticale may not be desirable when there is no shortage of wheat, it may be acceptable in countries aiming to reduce wheat imports. The milling quality of triticale should not be a constraint when it is used to produce wholemeal and high-ash flour baking products.

Bread making

Whole and refined triticale flours have been evaluated for their suitability in the preparation of baking products, such as different types of bread, oriental noodles and soft-wheat type products.

Leavened bread

Some studies (Lorenz, 1972; Kolkunova *et al*., 1983; Weipert, 1986) have shown that triticale and rye present few quality differences in relation to their baking

TABLE 1
Proximate composition of triticale, wheat and rye (dry basis)

Cereal	Protein (%)[a]	Starch (%)	Crude fibre (%)	Ether extract (%)	Free sugars (%)	Ash (%)	Reference[b]
Spring triticale	10.3-15.6	57-65	3.1-4.5	1.5-2.4	3.7-5.2	1.4-2.0	1, 2, 3
Winter triticale	10.2-13.5	53-63	2.3-3.0	1.1-1.9	4.3-7.6	1.8-2.9	4
Spring wheat	9.3-16.8	61-66	2.8-3.9	1.9-2.2	2.6-3.0	1.3-2.0	1, 2, 3
Winter wheat	11.0-12.8	58-62	3.0-3.1	1.6-1.7	2.6-3.3	1.7-1.8	4
Spring rye	13.0-14.3	54.5	2.6	1.8	5.0	2.1	1, 2

[a]Nx 5.7.
[b]1 = Bushuk and Larter, 1980; 2 = Peña and Bates, 1982; 3 = Johnson and Eason, 1988; 4 = Heger and Eggum, 1991. Data used in value ranges for spring triticale, spring wheat and spring rye were pulled out from one or more of the references indicated.

properties for preparing white-rye type and wheat-rye mixed breads. Triticale is acceptable for making rye bread because gluten protein-related factors, which are deficient in triticale, are not as critical as polysaccharides (starch and pentosans) and soluble proteins for rye flour dough and rye bread characteristics. Also, rye bread may be made from triticale flours with high levels of alpha-amylase activity, which is suppressed by acidic conditions prevailing during lactic fermentation used to produce this type of bread (Kolkunova *et al*., 1983; Weipert, 1986). Triticale flour may replace wheat or rye flour in the production of breads such as the American mixed wheat-rye bread, in which organic acids increase protein solubilization and, consequently, dough viscosity. Light rye bread can be made by blending wheat flour with triticale in a 60:85 ratio (Drew and Seibel, 1976). Alternatively, triticale may also be used to produce European rye-wheat or wheat-rye mixed breads (Ceglinska and Wolski, 1991; Háp and Pelikán, 1995; Sowa *et al*., 1995).

Triticale flours produce weak doughs due to low gluten content, inferior gluten strength and high levels of alpha-amylase activity (Macri, Balance and Larter, 1986a; Amaya and Peña, 1991). Weak dough is unsuitable for the manufacture of wheat-type leavened breads requiring medium-strong to strong dough properties, particularly pan-type breads and breads produced under high work-input conditions, as occurs in large baking plants and highly mechanized bakeries. Nonetheless, there is bread-making quality variability in triticale, and some triticale lines have been found to possess medium dough-strength character, acceptable for producing popular breads in Eastern Europe (Sowa *et al*., 1995; Sowa, Peña and Bushuk, 1998; Gryka, 1998; Täht *et al*., 1998; Tsvetkov and Stoeva, 2003).

Dense and flat breads

Some triticales can produce bread of acceptable quality under certain special bread-making conditions, such as low mixing speed and reduced fermentation times (Lorenz and Welsh, 1977; Amaya and Skovmand, 1985; Rakowska and Haber, 1991). This is particularly true for breads with dense crumb or flat-type breads prepared at home or in small bakeries where baking conditions are adjusted according to the quality attributes of the flour. Indian chapattis made with 100 percent triticale were found to be acceptable, except for their reddish colour (Sadiq, Saleem and Mohammad, 1985). However, the development of new triticale lines with white or amber grain colour (Sadiq, 1990; Naeem and Darvey, 1998) should overcome the undesirable reddish tint of triticale chapattis.

Wheat-triticale flour blends

The use of triticale in bread making seems more feasible in wheat-triticale flour blends; leavened breads with very acceptable quality attributes can be prepared with wheat-triticale flour blends containing up to 40 percent triticale. It has been shown that combining strong wheat flour and triticale flour with the best possible baking quality to prepare wheat-triticale flour blends containing 30 to 50 percent triticale may produce breads of a quality similar to, or even better than, that of 100 percent wheat breads (Lorenz and Ross, 1986; Bakhshi *et al*., 1989; Peña and Amaya, 1992; Naeem *et al*., 2002). Wheat-triticale wholemeal blends containing up to 50 percent triticale have been found to produce acceptable chapattis (Chawla and Kapoor, 1983; Ullah, Bajwa and Anjum, 1986).

Oriental noodles

Flour noodles, widely consumed in East Asia, are a staple food in northern China. Triticale flour has been evaluated

TABLE 2
Milling yields and ash content of wheat, triticale and wheat-triticale (75:25) grain blends[a]

Sample	Shorts (%)	Bran (%)	Flour (%)	Ash (%)
Wheat				
Hard	8.64	12.72	74.55	0.48
Semi-hard	10.02	14.33	71.69	0.42
Triticale				
Semi-hard	13.90	17.07	64.70	0.55
Soft	11.92	16.42	67.53	0.53
Grain blends[b]				
HW-SHTL	8.15	13.32	74.06	0.47
HW-STL	8.21	15.29	72.26	0.51
SHW-SHTL	9.83	13.74	71.94	0.46
SHW-STL	8.12	13.94	74.88	0.48

[a]Milling data for all samples and ash contents of grain blends adapted from Peña and Amaya, 1992.
[b]HW = hard wheat; SHW = semi-hard wheat; SHTL = semi-hard triticale; STL = soft triticale.

TABLE 3
Some physical and chemical characteristics of barley and triticale malts

Cereal and sample	Malt		Diastatic power	Amylase	
	Loss (%)	Extract (%)	(°)	β (*maltose equiv.*)	α (*20° units*)
Barley					
Dickson	8.0	76.6	115	361	30.4
Piroline	8.9	77.6	98	308	26.6
Hembar	7.8	71.6	68	222	15.3
Triticale					
6T204	9.7	78.8	253	804	62.9
6T208	9.3	75.1	252	822	58.2
6T209	11.2	77.9	231	704	66.0
6450-3-1	14.4	78.8	180	517	61.6
Rosner	10.2	82.4	140	422	45.6
6714	8.7	80.4	184	806	42.8
6804	8.7	80.8	173	558	44.7
6437-6	12.4	82.6	137	469	25.2
6450	12.3	81.9	161	483	50.8

Source: Adapted from Pomeranz, Burkhart and Moon, 1970.

for the manufacture of oriental noodles. Lorenz, Dildaver and Lough (1972) compared triticale flour with all-purpose flour in the preparation of regular and egg noodles. Dry regular noodles prepared with both flours were brittle, while egg noodles were hard. Thus, the cooking properties of triticale noodles were inferior to those of wheat noodles. Differences in the cooking quality of wheat and triticale flours decreased when egg was added, but no significant differences in noodle flavour were found. Lorenz, Dildaver and Lough (1972) concluded that triticale flour is suitable for the manufacture of both regular and egg noodles. In another study, Shin, Bae and Pack (1980) compared three locally grown winter wheats with introduced spring triticales in the preparation of Korean noodles. They found noodle-making quality differences among wheats and among triticales. Two of the three triticale lines tested produced Korean noodles of satisfactory quality. The main deficiency found in some triticale flours was the high (for noodle making) flour ash content, which imparts an undesirable greyish colour to the noodles. Modern triticales, particularly those with white or amber plump grain, should yield refined flour suitable for noodle making.

Soft-wheat type products

Triticales with soft grain texture are in general suitable for the manufacture of soft wheat flour-based baking products because the weak gluten properties that characterize triticale are favourable for the processing and quality of soft-wheat type products. Triticale flour has been found suitable for the production of layer cakes (Kissell and Lorenz, 1976; Lorenz and Ross, 1986). Optimal triticale flour performance in layer-cake making is achieved when straight-run flour is rebolted, pin-milled and chlorinated. The cookie-making quality of triticale is generally acceptable, but can be further improved by adding lecithin to the formula (Lorenz and Ross, 1986; Bakhshi *et al*., 1989; Leon, Rubiolo and Anon, 1996).

High-fibre extruded snacks

A formula containing 20 to 40 percent oat bran and wheat and triticale flours was extruded using a twin-screw to produce high-fibre snack bars that were comparable in most attributes with snack bars currently on the market but had significantly higher fibre content (Onwulata *et al*., 2000). Thus triticale is suitable for making nutritious health-food bars.

Malting and brewing

The ease with which triticale produces high levels of alpha-amylase activity has its positive side, as it allows triticale to perform well in malting and brewing. In general, triticale has larger malt losses but higher malt extracts, higher diastatic power and higher alpha- and beta-amylase activity than barley (Table 3) (Pomeranz, Burkhart and Moon, 1970). Gupta, Singh and Bains

(1985) additionally found that both duration of germination and level of steeping moisture significantly influenced malt losses; the largest malt losses and highest enzymatic (amylase and protease) activity were achieved when 42 percent steeping moisture (instead of 38 percent) and four to six days germination in the presence of gibberellic acid were used. One disadvantage of triticale malt is that it produces worts with high nitrogen content and high proteolytic activity, both of which promote dark colour, instability and haziness in beer (Pomeranz, Burkhart and Moon, 1970; Gupta, Singh and Bains, 1985; Lersrutaiyotin, Shigenaga and Utsunomiya, 1991). Lersrutaiyotin and Shigenaga (1991) found that among triticales used in their study, winter types had better malting quality than spring types, and complete triticales had better malting quality and lower total nitrogen content than substituted triticales. Pomeranz, Burkhart and Moon (1970) found that triticale beers were in general darker than barley beers; six of ten triticale beers had satisfactory clarity stability and seven showed satisfactory gas stability. The taste of triticale beer was acceptable.

Although there is malting quality variability in triticale, Holmes (1989) has indicated that it would be difficult to breed for this trait because there is no methodology available for rapid and simultaneous screening for both protein solubilization and carbohydrate modification.

FACTORS AFFECTING TRITICALE AS A FOOD GRAIN

The use of triticale as food is rather limited due to grain and non-grain factors. Although the poor processing quality of triticale is directly related to grain composition, it is also true that very little effort has been invested in breeding triticale for food uses. Non-grain factors, such as region-specific consumer preferences, competitiveness with other grains and economic and marketing issues, also affect triticale food use by limiting the supply of grain. These issues are briefly discussed in this section.

Grain factors

Considering milling and baking, the two main uses of its parent species, the grain factors that most affect processing quality and end-product characteristics of triticale are: grain size, shape and texture; flour-milling potential; enzymatic activity (particularly alpha-amylase); and protein (particularly gluten) and polysaccharide (particularly pentosan) composition. Although starch plays a major role in some baking products, it is not considered a problem for the food utilization of triticale, whose properties are basically the same as those of wheat and rye.

Physical characteristics

Triticale resembles wheat more than rye in terms of grain size, shape and colour. However, triticale grain is usually larger and longer than wheat grain. The grain of early triticales had a wrinkled appearance that ranged from slight to severe. Triticales developed in the late 1960s to the mid-1970s almost invariably produced shrivelled grains; however, this defect was gradually corrected after breeders started to apply selection pressure for plump grain. Today improved triticale cultivars have from plump to slightly shrivelled grain. Grain colour is generally red, but lines with more attractive colour (white and amber) have been developed (Sadiq, 1990; Naeem and Darvey, 1998). White and amber grain colour may be adequate for the production of flat breads, such as Indian chapattis, and baked products requiring white or amber grains.

Chemical composition

The chemical composition of triticale grain is essential for determining its potential end-uses. The nutritional aspects of grain composition are perhaps most important for feed uses of triticale, but the functionality of its grain components is critical for the manufacture of food products (particularly processed foods).

The proximate chemical composition of triticale grain is closer to that of wheat than rye, except for free sugar content, which is higher than that of wheat and closer to that of rye (Table 1). The wheat-like composition of triticale is most likely due to the fact that it received two genomes from wheat and only one from rye.

Amino acids

One of the traits that initially made triticale attractive as a crop was its good protein nutritional value, particularly its high (for a cereal) lysine content, the main limiting amino acid in cereal grains (Kies and Fox, 1970; Villegas, McDonald and Gilles, 1970). The high lysine levels found in the high-protein, shrivelled grain of early triticales have also been found in the plumper grain of more recent cultivars that nonetheless show lower protein contents (Johnson and Eason 1988; Mossé, Huet and Baudet, 1988; Heger and Eggum, 1991). Actually, lysine content has generally been found to be higher when protein content is low (Table 4) (Mossé, Huet and Baudet, 1988).

Proteins

Triticale's protein content is 10.0 to 16.0 percent

TABLE 4
Amino acid composition of triticale, wheat and rye varieties

Amino acid	Triticale[a]					Wheat[a]			Rye
	Dua	Towan	UH 116	Lasko	Lasko	Caton	Caton	Selekta	Petkus II
					(*g/16 g N*)				
Protein (Nx 5.7)	11.1	12.9	12.2	9.7	13.4	8.6	13.2	13.7	8.3
Gly	-	-	-	4.4	4.2	4.4	4.0	-	5.7
Ala	-	-	-	4.3	3.8	3.9	3.6	-	4.3
Val	4.7	4.6	4.4	4.9	4.6	4.6	4.4	3.6	4.7
Leu	6.6	6.4	6.0	6.4	6.4	6.8	7.0	6.5	6.4
Ile	3.6	3.6	3.3	3.9	3.7	3.5	3.7	3.4	3.8
Ser	-	-	-	4.5	4.5	4.8	5.4	-	2.9
Thr	3.4	3.3	3.0	3.5	3.2	3.2	3.2	2.8	2.8
Tyr	3.1	3.0	2.9	2.9	3.2	3.1	3.3	3.4	2.1
Phe	4.5	4.6	3.9	4.4	4.6	4.4	4.8	4.8	3.3
Trp	-	-	-	1.2	1.2	1.2	1.1	-	-
Pro	-	-	-	9.0	10.2	9.3	10.2	-	9.8
Met	1.7	1.7	1.8	1.9	1.6	1.8	1.5	1.9	-
Cys/2	2.5	2.6	2.6	2.7	2.6	2.6	2.6	1.9	-
Lys	3.4	3.1	3.2	4.0	3.4	3.4	2.7	2.8	3.8
His	2.3	2.3	2.5	2.3	2.2	2.4	2.3	2.5	2.7
Arg	5.3	5.1	4.5	5.5	5.0	5.2	5.0	4.7	5.0
Asp	-	-	-	6.8	5.9	5.5	5.0	-	7.3
Glu	-	-	-	25.2	26.8	25.9	30.6	-	22.7

[a]Varughese, Pfeiffer and Peña, 1996.

(Table 1), and its NaCl-soluble protein (albumins plus globulins) content is higher than that of wheat. The proportion of storage proteins (NaCl-insoluble) is lower in triticale than in wheat (Table 5).

Storage proteins interact to form gluten in wheat. Gluten quantity and quality are responsible for dough viscoelastic properties, which enable the production of a large variety of leavened and unleavened breads. The storage protein (NaCl-insoluble) content of triticale is considerably lower than that of wheat, and only part of it forms gluten (Table 5). In triticale, the portion of storage protein that does not form wheat-like gluten was inherited from rye. These differences in the amount and composition of storage proteins are the main factors responsible for the inferior bread-making quality of triticale as compared to wheat. Triticale bread-making dough shows deficient viscoelasticity and poor handling properties, and yields breads with low loaf volumes and compact crumb.

Triticale shows genetic variability for gluten content and gluten quality (Macri, Balance and Larter, 1986a; Peña and Balance, 1987; Peña *et al*., 1991; Peña, Mergoum and Pfeiffer, 1998). Table 6 shows the variability in gluten content and bread-making quality

TABLE 5
Protein solubility in 0.5M NaCl and gluten protein content of wheat, triticale and rye flours

Flour	NaCl-soluble (%)	NaCl-insoluble (%)	Gluten protein in flour protein (%)	Difference[a] (%)
Wheat	17.7	78.2	78.5	-0.3
Triticale (S)[b]	32.4	65.6	50.5	15.1
Triticale (C)[b]	32.5	64.2	46.4	17.8
Rye	36.7	63.0	-	-

[a]Difference is NaCl-insoluble minus gluten protein.
[b]S = substituted; C = complete. Data correspond to the mean of eight different lines in each case.
Source: Peña, 1996.

characteristics of two sets of triticale lines of contrasting bread-making quality. As shown in Table 6, there is bread-making quality variability at similar gluten content; therefore, in addition to gluten quantity, gluten quality is a major factor influencing the bread-making quality of triticale.

The highest gluten content in triticale is still 20 to 30 percent below that of wheat (Table 5), a situation that is difficult to improve substantially with the present gene

TABLE 6
Bread-making quality-related characteristics of spring hexaploid triticale groups possessing poor and good bread-making quality[a]

Bread-making quality group	Flour protein (%)	Dry gluten (%)	Flour SDSS[b] (ml)	Mixograph DDT[c] (min)	Bread loaf volume (ml)
Poor (n=46)[d]					
Mean	9.7a	6.3a	6.4a	1.5a	394a
Range	8.7-11.2	3.5-8.1	4.0-9.5	0.7-2.7	320-435
Good (n=46)[e]					
Mean	9.8a	6.2a	10.0b	2.5b	595b
Range	9.0-10.7	3.8-7.6	8.0-13.0	1.4-4.2	520-820

[a]Values within each column followed by the same letter are not significantly different (á = 0.05).
[b]SDSS = SDS-sedimentation volume (gluten strength-related parameter).
[c]DDT = dough development time.
[d]Poor bread-making quality = loaf volume < 440 ml.
[e]Good bread-making quality = loaf volume > 520 ml.
Source: Peña, Mergoum and Pfeiffer, 1998.

pool of triticale. However, further improvements in gluten quantity and quality through chromosome transformation seem feasible. Lukaszewski and Curtis (1992) induced translocations in triticale genotypes involving bread wheat chromosome 1DL, which carries genes encoding for high molecular weight subunits of glutenin that contribute greatly to bread-making quality, and triticale group 1 chromosomes. Quality evaluations of triticales carrying the 1DL gene pool (particularly the 1R.1D translocation) indicate that gluten quality in triticale can be further improved (Lukaszewski, 1998).

Enzymes: alpha-amylase activity

Mature, sound cereal grains are characterized by very low levels of enzymatic activity. Upon wetting, cereal grains tend to germinate (sprout), promoting an increase in enzymatic activity, which in turn hydrolyses starch and other grain components to sustain the development of a new plant. Greater than normal levels of enzymatic activity in sprouted grain may promote fungal development during storage or may have deleterious effects on the food-processing characteristics of cereals. Some triticales show high levels of alpha-amylase activity even in the absence of visual sprouting or spike wetting (Peña and Balance, 1987; Mares and Oettler, 1991; Trethowan *et al.*, 1993; Trethowan, Peña and Pfeiffer, 1994). Grain sprouting thus has important sanitation and economic implications.

Triticale has a tendency to sprout pre-harvest and to produce high levels of alpha-amylase activity (AAA). Pre-harvest sprouting is probably the most important grain-related factor that limits the food use of triticale. Particularly in bread making, it significantly alters the functional properties of starch and of the baking dough in which the starch is contained. The products of hydrolysis (sugars and gums) may also negatively alter end-use quality. Triticale exhibits large genetic variability for AAA and pre-harvest tolerance (Oettler and Mares, 1991; Trethowan, Peña and Pfeiffer, 1994), which has allowed breeders to select for low AAA.

From a different perspective, the tendency for triticale to produce high AAA could be advantageous in the production of triticale malt, which is used as an additive in the food industry, or in brewing. In the latter case, triticale malt has been found acceptable in relation to amylolytic activity and wort yields, but slightly high in proteolytic activity. This results in high levels of solubilized protein, which could cause problems during fermentation and storage (protein precipitation) and in the colour (dark) of the beer (Gupta, Singh and Bains, 1985; Holmes, 1989).

Enzymes: proteolytic activity

The proteolytic activity of triticale tends to be higher than that of wheat and, in some cases, even than that of rye (Madl and Tsen, 1974; Macri, Balance and Larter, 1986b). Madl and Tsen (1974) observed that the proteolytic activity of triticale varies greatly depending on genotype and/or growing location. From their bread-making results, Madl and Tsen (1973) and Macri, Balance and Larter (1986a) concluded that moderately high proteolytic activity would not be detrimental to bread-making quality, given that triticale flour had acceptable dough strength character.

Pentosans

Pentosans (arabinose plus xylose) are cell wall polysaccharides that play a major role in determining the viscous properties of rye flour dough required to produce good-quality rye bread. Pentosan content in rye flour determines dough yield, stability and volume, and partially influences bread-loaf volume and crumb texture. Proteins are important in rye flour dough but not to the same extent as in wheat flour dough (Drew and Seibel, 1976). Saini and Henry (1989) found that triticale had total and soluble pentosan contents similar to or slightly higher than those of wheat and much lower than those of rye (Table 7). In a different study, Fengler and Marquardt (1988) found that the flour soluble pentosan content and viscosity of water extracts were practically the same in wheat and triticale but significantly lower than those of rye (Table 7). Therefore, in the production of rye bread, triticale doughs would have inferior viscosity properties and baking quality as compared to doughs made with 100 percent rye flour.

TABLE 7

Pentosan content in grain and flour of triticale, wheat and rye

Cereal	Grain[a]		Flour[b]		
	Total (%)	Soluble (%)	Soluble (%)	Ash (%)	Viscosity (*water extract*)[c]
Triticale	7.60	1.82	0.05	0.70	1.39
Wheat	6.60	2.16	0.05	0.46	1.31
Rye	12.20	3.89	2.40	0.97	3.15

[a]Saini and Henry, 1989.
[b]Fengler and Marquardt, 1988.
[c]Values relative to water.

Flour and dough functional properties

Viscosity and other pasting properties of flour-water slurries depend greatly on starch properties. Although triticale's starch properties are similar to those of its parents, due to higher-than-normal levels of enzymatically (alpha-amylase) damaged starch, the paste viscosity of triticale flour-water slurries is often low compared to that of wheat (Lorenz, 1972; Weipert, 1986).

The rheological properties of triticale flour doughs have been extensively examined and compared with those of wheat and rye doughs. Studies using the Farinograph and the Mixograph (Lorenz *et al*., 1972; Lorenz and Welsh, 1977; Macri, Balance and Larter, 1986a; Rakowska and Haber, 1991) have shown that triticale flour doughs generally have lower water absorption, shorter dough development times and less mixing tolerance than wheat flour doughs. Studies using the Extensigraph and the Alveograph (Macri, Balance and Larter, 1986a; Weipert, 1986) have shown that triticale flours have dough strength values usually lower than those of wheat. Weipert (1986) indicated that triticale farinograms and extensigrams are more similar to those of rye than to those of wheat. On the other hand, Macri, Balance and Larter (1986a) and Peña, Mergoum and Pfeiffer (1998) have shown there is wide variability within triticale for dough strength-related properties; in some cases triticale doughs are more similar to weak to medium-strong wheat doughs than to rye doughs. It seems that there are rye-like and wheat-like triticale types.

Gluten protein content and gluten quality are the main factors affecting the viscoelastic properties of wheat flour doughs. Macri, Balance and Larter (1986a) and Peña and Balance (1987) showed that the same concepts apply to triticale; the weak dough character of triticale is influenced primarily by its low gluten protein content and by differences in the quality of its gluten-forming protein. At a more basic molecular level, differential quality (gluten strength-related parameters) effects have been associated with variations in high and low molecular weight glutenin subunit compositions (Ciaffi *et al*., 1991; Peña *et al*., 1991; Peña, Mergoum and Pfeiffer, 1998) and with the presence of secalins (rye proteins) in a triticale background (Ciaffi *et al*., 1991). In relation to quality effects, the above studies separately indicated that the high molecular weight subunit 13+16 and the low molecular weight subunit LMW-2, both controlled by genes located in the long and short arms, respectively, of chromosome 1B, should be superior to their counterparts 13+19 and LMW-1.

Recent studies on the diversity of glutenin and secalin of triticale cultivars grown in Europe have found large allelic diversity in glutenin and secalin proteins in winter and in spring triticales (Amiour *et al*., 2002a, 2002b). Examining the relationship between individual alleles and their combinations and gluten properties should allow us to determine which glutenin (and secalin) combinations are more desirable for improving gluten and dough viscoelasticity properties beyond what can be obtained with current triticale cultivars.

Non-grain factors

To avoid food-processing problems caused by grain compositional factors, triticale can partially replace wheat and/or rye flours in the preparation of baking products. In major triticale-producing countries, diverse baking

TABLE 8
Food uses of triticale in some major triticale-producing countries

Country	Product	Proportion of triticale flour (%)	Result[a]	Reference
Australia, New Zealand	Breads, cookies, biscuits	100, blend	+	Cooper, 1985, 1986; Lorenz and Ross, 1986; Naeem *et al.*, 2002
Brazil	Variety breads	40-100	+	Baier and Nedel, 1986
Germany	Leavened bread	40	+	Saurer, 1985
Poland	Rye-type bread	100	+	Rakowska and Haber, 1991; Sowa, Peña and Bushuk, 1998
Russian Federation	Rye-type bread	100, blend	+	Kolkunova *et al.*, 1983
United States of America	Layer cake	100, blend	+	Kissell and Lorenz, 1976

[a]Denotes positive experience with triticale as food.

products have been prepared successfully with triticale alone or by blending it with wheat and rye flours (Table 8). However, the food use of triticale remains very limited for reasons related to grain compositional factors (as previously discussed) and such non-grain factors as: (i) breeding issues; (ii) the fact that triticale is regarded as a feed grain and not promoted as a food crop; and (iii) marketing and processing difficulties. Some of these factors apply globally; others are region- or population-specific.

Breeding for quality

Breeding for grain size, shape and plumpness is highly desirable in order to achieve high test weight and acceptable flour-milling properties. Breeding for pre-harvest sprouting tolerance is necessary to maintain low, desirable levels of enzymatic activity and, consequently, good processing quality. Breeding for medium-hard to hard grain and for white grain colour would favour using triticale in wholemeal flat bread production as well as in noodle making. Finally, improving gluten strength by combining gluten proteins already present in triticale or incorporating alien gluten proteins would further increase the acceptability of triticale for bread production. Breeding triticale for malting quality has also proved feasible.

Although there are many issues to address in breeding triticale for food uses, formal triticale quality improvement seems not to occur (except in Australia) in breeding programmes. Possible reasons for this are:

- The perception that there is no need to improve triticale as a food grain because the local supply of traditional food grains is sufficient.
- Triticale quality improvement is desirable, but sources for quality improvement are not available.
- Triticale food quality improvement is desirable, but the required resources are not available.

In the latter two cases, it would be very useful to form international quality nurseries that group triticale lines according to their potential food use and an international network to help exchange and distribute triticale germplasm targetted for food uses.

Acceptability as a food grain

Despite agronomic and quality suitability, a new food grain for the preparation of traditional foods is not always well received. For example, Algeria imports large amounts of wheat for bread production. In an attempt to reduce wheat imports, triticale was tested and found suitable for bread making if used in wheat-triticale blends (70-30); however, it could not be utilized because people were not yet prepared to accept the use of cereals other than wheat in bread making (Benbelkacem, 1987). Another factor influencing the adoption of triticale is how well it competes with other cereals; for example, barley is a better cash crop than triticale in Algeria (Benbelkacem, 1987) and oat is better in central Mexico (Carney, 1990). Finally, acceptability may be limited due to socio-political factors. For instance, in some parts of Europe triticale is officially recognized as a feed grain not suitable for food uses (A. Kratigger, personal communication, 1995).

Promotion as a food crop

Promotion could play a very important role in gaining acceptance for triticale. Once non-grain problems have been solved, the lack of promotion becomes the main factor limiting the use of triticale as a food grain. The type of promotion required will vary according to the targetted area, population, or sector. Smallholders need to be shown that triticale has a role to play in sustainable farming systems as a low-input cereal and/or dual-purpose crop (food and feed) that fits local crop rotations. Among consumers looking for nutritious foods, it should be promoted as a good source of energy, lysine and dietary fibre. At the end-use level, triticale should be promoted as good for making local, cereal-based foods and new, non-conventional foods (snacks and breakfast cereal), and also as a raw material in the food industry (starch production and malted triticale).

Marketing and food processing

A reliable grain supply is a prerequisite for establishing a triticale market, but farmers often claim that they require a well-established market before they set up production. Marketing is also difficult due to the lack of official grading factors and price for triticale. In addition, disappointing results have sometimes been obtained from milling, baking and malting tests conducted at the industrial level in which triticale has received the same treatment as wheat or barley. This is not appropriate, but has occurred because the industry has little experience in processing triticale. However, when certain feasible modifications have been made, satisfactory results have been obtained. In these cases, the unwillingness of food processors to make these changes has become the limiting factor.

UTILIZATION

Although triticale is now commercially grown on approximately 3 million ha, there is little published information on its commercial utilization. Studies on the potential food and feed utilization of triticale in the last 25 years are numerous, however.

Although in many cases triticale has proven suitable as a food grain (Table 8), its food use has not reached the commercial level. Given its generally inferior wheat-like bread-making quality, triticale flour is not considered suitable for bread making, particularly if wheat flour is available. In a few cases, when wheat has been in short supply, triticale has been used, particularly by small landholders, alone or blended with wheat, for the manufacture of local home-made breads, for example, sweet breads in the highlands of central Mexico (Carney 1990), local breads in southern Brazil (Baier and Nedel, 1986) and chapattis in northern India (Biggs, 1982). Small amounts of rolled triticale ('flakes'), wholemeal flour, wholemeal speciality breads and other health foods have been marketed in Australia (Cooper, 1986).

In summary, several grain and non-grain factors have caused triticale to fail as a commercial food grain. The global wheat surplus, lack of year-to-year consistency in triticale grain supply and possibly in grain quality (as related to year-to-year variations in environmental conditions promoting grain sprouting and/or year-to-year differences in crop management affecting grain plumpness and grain protein content), absence of official triticale grading systems and lack of proper promotion are other factors that do not allow the formation of the farmer-industry-consumer chain necessary for triticale to become established as a commercial food grain.

CONCLUDING REMARKS

The utilization of triticale as a food grain is influenced by grain and non-grain factors. Despite important grain compositional problems, triticale can be used as a food grain, mainly as a replacement of wheat and rye flour in proportions that will depend on the type of baking product. Further improvements, particularly in grain plumpness, grain colour (white or amber) and gluten quantity and quality, are expected to make triticale more attractive as a food grain. As has been suggested (N. Darvey, personal communication, 1996), global networking among breeding programmes willing to improve triticale quality could play a determining role in germplasm exchange and in accelerating triticale quality breeding. However, no action has been taken so far. This may be due to the economic problems facing breeding programmes all over the world. Thus non-grain factors, which are diverse, complex, and in many cases region- and population-specific, may limit the food use of triticale more than grain-related factors.

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Triticale as animal feed

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Triticale has been produced for many years. Advances in plant breeding have made triticale a viable crop in many parts of the world. Much of the production is as triticale grain, but triticale is also grown as a forage crop and as a dual-purpose crop (both forage and grain). The grain is primarily used for feeding pigs, but it can be and is fed to poultry and ruminant animals, such as cattle and sheep. As forage, the crop can be and is grazed by cattle and sheep, or harvested for silage or hay. Triticale also produces an abundant amount of straw.

Early on, interest in triticale as a feed grain was generated because of its higher protein concentration and better amino acid balance as compared to other feed grains such as maize. Production problems, including variable yield, pre-harvest sprouting and light-weight, shrivelled kernels, and nutrition problems, such as low energy density, variable composition and low palatability, have detracted interest (NRC, 1989; Myer, Combs and Barnett, 1990; Hill, 1991; Varughese, Pfeiffer and Peña, 1996; Boros, 2002). Plant breeders over the last 30 years, however, have greatly improved the crop. Modern triticale grain varieties are high yielding, and yield grain is plumper and has a heavier test weight than the older varieties. Plant breeders also have and are developing varieties specifically for forage and for dual purposes.

TRITICALE AS A FEED GRAIN

The increase in grain plumpness of modern triticale varieties has resulted in grain of higher starch content and thus more energy dense than was typical of the older, shrivel-seeded, light-weight varieties (NRC, 1989; Varughese, Pfeiffer and Peña, 1996; Boros, 2002). The increase in starch content, however, has resulted in grain with a lower protein concentration than the older varieties (NRC, 1989; Myer, Combs and Barnett, 1990; Varughese, Pfeiffer and Peña, 1996; Boros, 2002; Van Barneveld, 2002). Protein content and quality, nevertheless, are still greater than most other cereal feed grains (NRC, 1989; Myer, Combs and Barnett, 1990; Varughese, Pfeiffer and Peña, 1996; Boros, 2002; Van Barneveld, 2002). Of its two parents, modern triticale grain resembles wheat more than rye in regards to grain morphology, with its test weight slightly lower than that of wheat (NRC, 1989; Varughese, Pfeiffer and Peña, 1996; Boros, 2002; Van Barneveld, 2002).

Triticale grain is a relatively soft grain with a hardness index almost half of that observed for wheat and barley (Van Barneveld, 2002). The advantage is that less mechanical energy would be required to process triticale grain (i.e. grinding and rolling) compared to wheat and barley prior to mixing into livestock diets. The softer triticale grain, however, may be more susceptible to insect damage during storage than other feed grains (Van Barneveld, 2002). Care must be taken in regards to long-term storage of triticale grain.

Nutrient composition

Modern triticale is higher than maize in protein and essential amino acids, in particular lysine, which is usually the most limiting essential amino acid in typical pig diets[1]. Modern, high-yielding triticale cultivar grain is similar to or slightly lower than wheat in protein; however, lysine and threonine concentrations, as a percentage of the protein, are typically higher (Table 1) (NRC, 1989, 1998; Myer, Combs and Barnett, 1990; Radecki and Miller, 1990; Varughese, Pfeiffer and Peña, 1996; Boros, 2002; Van Barneveld, 2002). The higher concentrations of limiting essential amino acids, in particular lysine and threonine, permit less use of a supplemental protein source, such as soybean meal, when using triticale as opposed to maize in formulating diets for pigs and poultry. It should be pointed out, however, that much variation exists in the protein and amino acid concentrations of triticale. Protein and lysine concentrations of 9 to 18 percent and 0.33 to 0.71 percent, respectively, have been reported in the literature (Pettersson and Aman,

[1]Lysine content is important because pigs, like most simple-stomached, non-ruminant animals, do not require protein *per se*, instead they require specific levels of certain compounds that make up protein. These compounds are called amino acids. Some of these amino acids, termed essential amino acids, must be present in the diet for pigs to grow and perform well. A few essential amino acids tend to be limiting in typical pig diets. One essential amino acid, lysine, is usually the most limiting or first-limiting amino acid. This means that if a diet is formulated to supply the correct amount of lysine, then generally the levels of the other essential acids will be adequate. Therefore, lysine concentration is an important consideration when comparing cereal grains.

TABLE 1
Comparative composition of triticale, maize and wheat grain (as-fed basis)

Item	Triticale	Maize	Wheat[a]
Crude protein (%)	12.0	8.5	11.5
Lysine (%)	0.40	0.24	0.34
Crude fibre (%)	2.8	2.2	2.4
Acid detergent fibre (%)	3.8	2.8	3.5
Neutral detergent fibre (%)	12.7	9.6	11.0
Crude fat (%)	1.8	3.8	1.8
Calcium (%)	0.05	0.02	0.05
Phosphorus (%)	0.33	0.25	0.33
Metabolizable energy in pigs (*kcal/kg*)	3 200	3 350	3 350
Metabolizable energy in beef cattle (*kcal/kg*)	3 180	3 180	3 180
Metabolizable energy in poultry (*kcal/kg*)	3 200	3 400	3 210
Total digestible nutrients for ruminants (%)	79	80	79

[a]Soft red winter wheat.
Source: Radecki and Miller, 1990; Myer, Combs and Barnett, 1990; NRC, 1998, 2000; Hughes and Choct, 1999; Gursoy and Yilmaz, 2002; Van Barneveld, 2002.

1987; Radecki and Miller, 1990; Heger and Eggum, 1991; Leterme, Thewis and Tahon, 1991; Varughese, Pfeiffer and Peña, 1996). The variation is due to differences in cultivar and crop-growing conditions, such as soil fertility (Pettersson and Aman, 1987; Heger and Eggum, 1991; Feil and Fossati, 1995; Varughese, Pfeiffer and Peña, 1996; Moinuddin and Afrid, 1997; Bruckner, Cash and Lee, 1998). In general, the older cultivars will have higher protein levels than the newer ones.

The energy content of modern triticale grain cultivars averages about 95 to 100 percent of that of maize or wheat for non-ruminants (pigs and poultry) (Batterham, Saini Anderson, 1988; Charmley and Greenhalgh, 1987; Batterham, Saini and Baigent, 1990; Hill, 1991; Myer, Combs and Barnett, 1991; Flores, Castanon and McNab, 1994; Vieira *et al.*, 1995; NRC, 1998; Boros, 2002; Van Barneveld, 2002; Van Barneveld and Cooper, 2002). For ruminant animals, energy concentration has generally been found to be comparable to maize, barley or wheat (Charmley and Greenhalgh, 1987; ZoBell, Goonewardene and Engstrom, 1990; Hill, 1991; McQueen and Fillmore, 1991; NRC, 2000). The digestibility of protein and amino acids in triticale grain has been found to be quite good, being similar to or even slightly better than that observed for maize or wheat (Coffey and Gerrits, 1988; Myer *et al.*, 1989; Radecki and Miller, 1990; Hill, 1991; Van Barneveld, 2002).

Concentrations of various minerals in triticale grain are similar to those of wheat (NRC, 1989, 1998; Radecki and Miller, 1990; Varughese, Pfeiffer and Peña, 1996; Van Barneveld, 2002). As in wheat, the phosphorus level is higher than in maize, and more of the phosphorus is digestible for non-ruminants (NRC, 1989, 1998; Radecki and Miller, 1990; Leterme, Thewis and Tahon, 1991; Van Barneveld, 2002). Typically, 40 to 50 percent of the phosphorus in triticale and wheat is available (digestible), whereas only 20 to 30 percent is available in maize (NRC, 1998). The higher level and greater availability of phosphorus allows for less phosphorus supplementation when using triticale in diet formulation as opposed to maize.

Undesirable constituents in triticale grain

Prior to 1975, there were reports in the literature of various anti-nutritional factors that may have been responsible for reduced intake and performance of animals consuming triticale-based diets (NRC, 1989; Radecki and Miller, 1990; Hill, 1991; Boros, 2002). With modern triticale, various anti-nutritional factors, such as non-starch polysaccharides (pentosans) and protease inhibitors, while higher than in most other cereal grains, seem to have no effect on the growth performance of livestock consuming diets containing triticale grain (NRC, 1989; Batterham, Saini and Baigent, 1990; Radecki and Miller, 1990; Boros and Rakowska, 1991; Boros, 2002; Myer, 2002; Van Barneveld and Cooper, 2002). The possible exception is the anti-nutritional effect of pentosans in poultry nutrition. Poultry are rather sensitive to the anti-nutritional effects of these compounds. Pentosans are also present in wheat and rye. Pentosans in wheat and rye are known to interfere with digestion and absorption of various nutrients (Pettersson and Aman, 1988; Annison and Choct, 1991; Bakker *et al.*, 1998; Cheeke, 1998; Boros, 1999, 2002; Im *et al.*, 1999).

TABLE 2
Example pig diets using triticale grain

Ingredient	Grower (20-50 kg)	Finisher I (50-80 kg)	Finisher II (80-110 kg)
Ground triticale (%)	74.25	82.75	90.000
44% soybean meal (%)[a]	22.50	15.00	8.000
Base mix[b]			
Dicalcium phosphate (%)[c]	1.25	0.75	0.625
Limestone, ground (%)	1.00	1.00	0.875
Salt (%)	0.50	0.25	0.250
Vitamin-trace mineral premix (%)[d]	0.50	0.25	0.250
	100.00	100.00	100.000
Calculated composition (as-fed basis)			
Crude protein (%)	18.8	16.5	14.4
Lysine (%)	0.96	0.77	0.60
Calcium (%)	0.75	0.62	0.55
Phosphorus (%)	0.64	0.53	0.48
Metabolizable energy (*kcal/kg*)	3 150	3 170	3 200

[a]Can replace ten parts of 44 percent soybean meal with nine parts of 48 percent soybean meal and one part of triticale.
[b]A complete mineral-vitamin premix or a complete mineral premix and separate vitamin premix may be used instead of the suggested base mix. Follow manufacturer guidelines.
[c]Defluorinated phosphate or mono-dicalcium phosphate, if available, may be substituted for dicalcium phosphate. However, if a substitution is made, the diets need to be reformulated since these products contain different calcium and phosphorus levels than dicalcium phosphate.
[d]Amounts shown are typical for many commercial products. Follow manufacturer guidelines.
Source: Myer and Barnett, 1984.

Ergot infection, while a potential problem for triticale grown under cool and wet conditions, seems to occur much less in the new triticales than previously noted with the older cultivars (NRC, 1989). As with other cereals, triticale is susceptible to contamination by various moulds that can produce toxic mycotoxins, in particular scab, resulting in the accumulation of deoxynivalenol (DON) in the grain (Goral, Perkowski and Arseniak, 2002). Triticale grain, like wheat, however, is somewhat resistance to aflatoxin contamination (Bilotti, Fernandez-Pinto and Vaamonde, 2000).

GRAIN USES

Triticale grain for pig feeding

Modern triticale grain cultivars provide an excellent feed grain for use in mixed pig diets. Research has shown that triticale grain is a satisfactory replacement for maize, and because of its superior lysine content, it can replace part of the supplemental protein source, such as soybean meal, in typical maize-soybean meal based diets for all classes of pigs (Hale, Morey and Myer, 1985; Coffey and Gerrits, 1988; Myer *et al.*, 1989; NRC, 1989; Batterham, Saini and Baigent, 1990; Myer, Combs and Barnett, 1990; Radecki and Miller, 1990; Hill, 1991; Leterme, Thewis and Tahon, 1991; Myer, Brendemuhl and Barnett, 1996; Boros, 2002; Myer, 2002; Van Barneveld and Cooper, 2002).

Even though triticale grain contains more protein than maize or grain sorghum, diets should be formulated to meet the essential amino acid (especially lysine) requirements of the pig rather than the crude protein requirements. If diets containing triticale were formulated on the basis of crude protein alone, lysine levels could be inadequate and pig performance would suffer.

Because of the higher lysine content of triticale grain, farmers who mix their own diets using a protein supplement (i.e. soybean meal) plus a premix programme can save a substantial amount of the protein supplement per tonne of mixed diet over comparable maize or grain sorghum based diets. Examples of diets formulated with triticale are given in Table 2. The crude protein concentration of triticale-based diets is usually higher than that of comparable maize-based diets when both diets contain equal levels of lysine. The example diets are also formulated to take advantage of the higher level of phosphorus of triticale, resulting in a savings of 2.5 kg of dicalcium phosphate per tonne of diet over comparable maize-based diets. This gives an advantage to farmers who mix their own diets with any premixes.

The relative energy value of modern triticale grain, based on results of the research mentioned above, is about 95 to 100 percent of maize for pigs. Triticale should be ground or rolled for use in pig diets. A medium grind is preferred (no whole kernels should be visible). Finely ground triticale is not desirable because it easily absorbs moisture from the atmosphere and the pig's own saliva, which can result in feed spoilage and reduced feed intake.

Triticale grain for poultry feeding

As with pigs, modern triticale grain is a good feed grain for use in mixed poultry diets. The energy content of modern triticale grain for broilers and laying hens is comparable to other cereals, such as wheat, barley or grain sorghum. Apparent metabolizable energy (AME) concentrations of 12.8 to 14.3, 10.4 to 15.9, 10.4 to 12.2 and 14.9 to 15.8 mJ/kg for triticale, wheat, barley and grain sorghum, respectively, have been reported (Hughes and Choct, 1999).

As mentioned above for pigs, diets formulated with triticale should be on a limiting essential amino acid basis (i.e. lysine) and not on a protein basis. Even though poultry can utilize whole kernels, triticale grain should be ground or rolled to ensure proper mixing with other diet ingredients for a balanced diet.

As mentioned above, poultry are sensitive to the anti-nutritional effects of various non-starch polysaccharides, such as pentosans, more so than pigs and other livestock. Pentosans present in wheat and rye have been shown to depress the energy value of wheat for poultry by 5 to 10 percent and even more for rye (Pettersson and Aman, 1988; Annison and Choct, 1991; Cheeke, 1998; Im *et al.*, 1999; Boros, 2002). Pentosans may also result in the excretion of wet, sticky droppings. The anti-nutritional effect can be overcome with the addition of commercially available feed enzymes (primarily xylanases). Even though triticale typically contains higher levels of pentosans than wheat (but lower than rye), results are mixed regarding the effectiveness of these enzymes on improving the nutritive value of triticale (Pettersson and Aman, 1988; Bakker *et al.*, 1998; Boros, 1999, 2002; Im *et al.*, 1999). Thus the pentosans from triticale may not have the anti-nutritive effect as with other cereals. Nevertheless, if available, typical recommendations are to include an enzyme supplement, not so much to improve triticale but to improve the feed value of contaminate grains, such as rye and wheat, which may be present in feed-grade triticale grain (Boros, 2002).

Unlike maize, triticale grain contains no pigments (i.e. carotenoids and xanthophylls). If dark-yellow egg yolks and yellow-skinned broilers are desired, then a pigment source (i.e. corn gluten meal and dehydrated alfalfa meal) would have to be added to diets containing a high level of triticale (El Boushy and Raterink, 1992).

Triticale grain for ruminants

Ruminant animals (i.e. cattle, sheep, goats, deer, camels, buffalo and llamas) have an enlarged four-compartment stomach. Unlike non-ruminants, such as pigs and poultry, microbes (mostly bacteria) within the rumen (the first compartment) of ruminants can significantly alter nutrients flowing to the small intestine for absorption. Therefore, these microbes within the rumen can allow a ruminant animal to utilize high-fibre forages and low-quality protein sources that cannot be efficiently utilized by non-ruminants. Thus, in regards to protein, a feed formulator is more concerned about protein quantity rather than protein quality when formulating diets for ruminants as opposed to non-ruminants. However, because of this symbiosis with microbes within the rumen, rapid dietary changes are of more concern when feeding ruminants than non-ruminants. Rapid changes can cause digestive problems, such as bloat and acidosis.

Triticale grain is a good feed grain for cattle, sheep and other ruminants. Triticale grain can replace part or all of the maize, grain sorghum or other cereal grain in diets for these animals. Grain from modern triticale varieties has been reported to be comparable in energy value to other cereal grains for use in the mixed diets of beef and dairy cattle and sheep, and its protein is well utilized (Charmley and Greenhalgh, 1987; ZoBell, Goonewardene and Engstrom, 1990; Hill, 1991; McQueen and Fillmore, 1991; Brand and van der Merwe, 1994; Miller *et al.*, 1996; NRC, 2000; Gursoy and Yilmaz, 2002). Because of its relatively high protein content, additional protein supplementation may not be necessary in many cases (i.e. for finishing beef cattle) when triticale is used as the grain source. The starch in triticale, like wheat, is readily fermentable by the rumen microbes. For the most efficient use of its available energy, triticale should be blended with another feed grain with slower fermentable starch, such as maize or grain sorghum. In addition, care must be taken to avoid sudden diet changes to diets containing triticale grain, especially if a high level is used. Triticale grain should be processed (i.e. grinding, rolling and flaking) before mixing it into the diet.

FORAGE USES

Triticale forage for ruminants

Triticale has been and is increasingly grown for livestock grazing, cut forage (green chop), whole-plant silage, hay and forage/grain dual purpose. Worldwide, there are hundreds of different varieties of triticale, many of which have been developed for forage production. These varieties differ in winter hardiness, growth habit and

TABLE 3
Average composition of triticale forage

Item	Fresh forage	Silage[a]	Hay[a]
Dry matter (%)	20	35	89
Crude protein (*% dry matter*)	20	12	8
Acid detergent fibre (*% dry matter*)	30	35	40
Neutral detergent fibre (*% dry matter*)	50	60	70
Calcium (*% dry matter*)	0.4	0.4	0.2
Phosphorus (*% dry matter*)	0.3	0.3	0.2
Total digestible nutrients for ruminants (*% dry matter*)	(70)[b]	60	55
Metabolizable energy in beef cattle (*kcal/kg dry matter*)	(2 500)[b]	2 200	2 000

[a]Early-dough stage.
[b]Estimated.
Source: Sun and Wang, 1991; ZoBell, Goonewardene and Engstrom, 1992; Khorasani *et al.*, 1993; McCartney and Vaage, 1994; Royo and Tribó, 1997; Juskiw, Salmon and Helm, 1999; Maloney, Oplinger and Albrecht, 1999; Juskiw, Helm and Salmon, 2000; NRC, 2000.

productivity. The majority of triticale cultivars have prominent awns; however, some recent releases are awnless, thereby further increasing the potential for triticale as a forage crop (Gibson, 2002).

In general, dry-matter yield of forage for triticale compares very favourably to other small-grain forage cereals in studies done all over the world (Varughese, Barker and Saari, 1987; NRC, 1989; Jedel and Salmon, 1994; McCartney and Vaage, 1994; Varughese, Pfeiffer and Peña, 1996; Lozano *et al.*, 1998; Juskiw, Salmon and Helm, 1999; Maloney, Oplinger and Albrecht, 1999; Juskiw, Helm and Salmon, 2000; Rao, Coleman and Volesky, 2000). There is much variation, however, among triticale cultivars. Research on the evaluation of triticale as forage for ruminants has generally indicated comparative nutritive values to other forage cereal crops (Bruckner and Hanna, 1990; Andrews *et al.*, 1991; Carnide *et al.*, 1991; Sun and Wang, 1991; ZoBell, Goonewardene and Engstrom, 1992; Khorasani *et al.*, 1993; Jedel and Salmon, 1994; McCartney and Vaage, 1994; Varughese, Pfeiffer and Peña, 1996; Lozano *et al.*, 1998; Maloney, Oplinger and Albrecht, 1999; Juskiw, Helm and Salmon, 2000; Rao, Coleman and Volesky, 2000). Nutrient composition generally follows that of other forage cereal crops (Table 3) (Bruckner and Hanna, 1990; Lozano, 1990; Sun and Wang, 1991; Wright, Agyare and Jessop, 1991; ZoBell, Goonewardene and Engstrom, 1992; McCartney and Vaage, 1994; Maloney, Oplinger and Albrecht, 1999; NRC, 2000).

Triticale forage types

Triticale cultivars, grown for forage as well as for grain, can be classified into three basic types according to growth habit: spring, winter and intermediate (facultative).

Spring types, which do not require vernalization to go from vegetative to reproductive stages, are generally planted during the spring, but can be planted in the autumn in milder climates. Spring types exhibit upright growth and produce much forage early in their growth. They are insensitive to photoperiod and have limited tillering. Winter types, which need vernalization to go from vegetative to reproductive phases, are generally planted in the autumn, but can also be planted in the spring in some situations. Winter types have a prostrate type of growth in the early stages of development. In general, winter types yield more forage than spring types mainly due to their long growth cycle. Intermediate (facultative) types, as the name implies, are intermediate to spring and winter types, but do not require vernalization to evolve into the reproductive phase.

Spring triticale provides an excellent alternative to other spring cereals, such as barley and oats. Spring triticale has been shown to be more drought tolerant than other spring cereals (Hinojosa *et al.*, 2002). Facultative and winter types are particularly well suited for grazing as they generally have a better distribution of forage over the growing season (Lozano, 1990).

Potential forage systems

Triticale can be grown as a mono-crop, winter/spring blend, mixed with legumes, or mixed with other cereals and/or annual ryegrass. The advantage with blends is that the grazing season can be extended and/or forage nutritive value improved, in particular when blended with legumes.

Mono-crop (monoculture)

Results of studies done at various locations around the world have generally indicated that triticale performs well when compared to other small grains, such as barley, oats and wheat, in particular under dryland conditions (NRC, 1989; Jedel and Salmon, 1994; McCartney and Vaage, 1994; Stallknecht and Wichman, 1998; Juskiw, Salmon and Helm, 1999; Maloney, Oplinger and Albrecht, 1999; Rao, Coleman and Volesky, 2000; Hinojosa *et al.*, 2002; Juskiw, Helm and Salmon, 2000).

Winter-spring mixtures

Depending upon location, a mixture of a winter and spring type can be planted together in the autumn (mild climates) or spring. The advantage is that forage production is distributed more evenly over the growing season and the growing season can be extended. This option would be particularly advantageous for grazing.

Triticale-small grain mixtures

Mixtures of triticale with other cereals, in particular barley, work well in the production of high-quality silage. Advantages for these mixtures include extension of harvest period, disease control and decreased lodging.

Triticale-annual ryegrass mixtures

Initial grazing field research has suggested that planting triticale and ryegrass in combination could lengthen the grazing season, improve the trampling tolerance of the annual pasture and improve palatability when compared to their monocultures (Lozano del Río *et al.*, 2002). The nutritional quality was found to be similar to their monocultures (Lozano del Río *et al.*, 2002). Triticale has also been found to persist longer than rye in mixtures with ryegrass (NRC, 1989).

Triticale-legume mixtures

Intercropping legume crops with small-grain cereal crops can be an effective way to improve forage quality and the nutritive value of the crop. This cultural practice is particularly well suited for silage production. The best relationships between yield and quality were generally obtained when the cereal reached boot stage and the legume reached flowering stage (Carnide *et al.*, 1998). Mixtures where triticale was the cereal showed an advantage over mixtures with other cereals (barley and oats) in overall forage quality due to a higher proportion of legume in the forage crop harvested (Benbelkacem and Zeghide, 1996). This is due to the more upright growth habit of triticale compared to oats and barley. Mixtures with field peas (*Pisum sativum*) and hairy vetch (*Vicia villosa*) seem to work best not only for silage but also for hay production (Carnide *et al.*, 1998).

OTHER USES

Triticale as a grazing crop

Triticale can be and is planted as an annual crop to be grazed by ruminants. Triticale varieties are available that have been specifically selected for grazing. Depending upon location, the crop can be planted in the autumn or spring. To extend the grazing season, autumn varieties can be planted as a mono-crop or in a blend with spring varieties in the spring in cold climates. In warmer climates, the crop can be and is planted in the autumn, and depending upon moisture and temperature, can be grazed starting early the following spring. The crop is grazed until it senesces in early summer. Forage quality and biomass yield usually decline after heading. In colder climates, the crop can be grazed starting late spring and grazed through the summer and even into autumn.

Grazing should be started when the plants are about 25 to 30 cm high and before jointing. This will occur six to eight weeks after plant emergence for most grazing types under good growing conditions. Plants should not be grazed lower than 7 to 10 cm. Severe over-grazing should be avoided. Triticale grows rapidly in the spring, and as the plant nears maturity, nutritional quality declines. Early growth is quite lush and high in moisture, and diarrhoea in the animals is common at this stage of grazing. Providing dry-grass hay or straw while grazing can help minimize diarrhoea. A complete cattle-grazing mineral mix free choice is recommended while animals are grazing.

Triticale as silage

The cutting and subsequent storage of triticale forage for silage is similar to that of any small-cereal forage. The harvest date of triticale for silage is very important. As plants develop beyond the boot stage and into early grainfill, the protein and energy levels drop while the fibre level rapidly increases. Although there is a general increase in dry-matter yield as the crop matures, the increased yield is more than offset by the reduction in forage quality. Consequently, the best time to cut triticale for silage is in the boot to early-heading stage. Triticale cut earlier than the soft-dough stage will require wilting in order to make high-quality silage. The length of wilting time required will vary, depending on the drying conditions and stage of maturity. Approximately 35 to 40 percent dry matter is desirable for ensiling. Cutting length should be 1 to 5 cm for good ensiling. Silage should be packed tightly to exclude as much air as possible.

Generally, most cereal forages are cut for silage in

TABLE 4
Protein content and *in vitro* digestibility at different phenological stages of wheat, oat and facultative triticale in northern Mexico (dry matter basis)

Species	Protein content (%)			*In vitro* digestibility (%)		
	Stage of growth			Stage of growth		
	Jointing	Boot	Dough	Jointing	Boot	Dough
Wheat	20	17	7	75	73	58
Oat	21	19	12	77	72	58
Triticale	27	19	8	79	76	58

Source: Anonymous, 2001.

the soft-dough to mid-dough stage. Results of some trials with triticale suggest it would be best to cut earlier (i.e. boot stage) (Table 4) (Anonymous, 2001). Harvest at later stages of development will result in a greater yield, but quality will be lower. This forage (silage and hay) would be better suited for dairy dry cows and heifers, and beef cattle.

Triticale as a dual-purpose forage/grain crop

Triticale can be and indeed is used as a dual-purpose crop. In a dual system, triticale is grazed in a similar way as described above, but the animals are removed at plant jointing. The forage can also be cut for green chop or silage up to jointing. The triticale will then mature, and a grain crop is harvested. There are several advantages of this system other than the harvest of forage; for instance, the grain crop is less likely to lodge. A major disadvantage is that there is usually some grain yield loss, usually a 5 to 20 percent reduction (Andrews *et al.*, 1991; Wright, Agyare and Jessop, 1991; Royo, 1997; Royo and Tribó, 1997). Grain yield depends upon environmental conditions, moisture, soil fertility, plant genotype and stage of growth at the time of clipping or grazing. The yield decrease has been mainly due to reduced spike density and/or smaller grain kernels.

Triticale as a hay crop

Triticale, as with other small grains, can provide a good source of hay when properly cut, cured and baled. For best results and quality, triticale should be cut between late-boot and early-heading stages.

Triticale straw

Straw is an important by-product of triticale grain production and is often overlooked. Triticale produces more straw than other small-grain cereals. Straw is frequently the only source of livestock feed in developing countries (Mergoum, Ryan and Shroyer, 1992; Mergoum and Kallida, 1997). In general, nutritive value compares favourably with wheat straw, but there are large variety differences (Flachowsky, Tiroke and Schein, 1991).

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Triticale marketing: strategies for matching crop capabilities to user needs

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Marketing ideally begins by identifying the needs of potential customers, then developing products and marketing programmes to meet those needs. In practice, however, marketing often begins with a product that a developer or producer envisions can satisfy needs. That general vision about product potential leads to marketing efforts to find and serve specific customers who can benefit from the product. Although some marketers may discover triticale in their search for solutions to specific customer needs, most marketers now involved with triticale begin with a vision or belief that triticale can satisfy important needs, then strive to find specific uses and customers for which the crop provides value.

The primary objective of this chapter on triticale marketing strategies is to help farmers, triticale breeding organizations, seed suppliers, policymakers, agricultural development groups and others involved with or interested in triticale to identify, develop and fulfil marketing opportunities for this crop. The chapter also may alert those seeking solutions to specific needs that triticale may provide such a solution. The chapter begins with a general overview of triticale marketing encompassing all product levels (genetics, seed, forage and grain), then outlines a general framework for developing marketing strategies for triticale and concludes with specific examples of triticale marketing strategies.

Triticale marketing began with the first developers of the crop who envisioned how it could provide important benefits. As a result of that vision and over fifty years of plant breeding, production and use of triticale by dedicated "crop champions" (Waters, 1988) all over the world, triticale has become an important option for providing grain and forage and protecting the environment (Mergoum *et al.*, 1998). Whether in an area where triticale is not yet used, or one in which the goal is to expand that use, the marketing challenge is to match up the capabilities of triticale with specific human needs that triticale can meet more effectively and economically than other crops.

The specific marketing challenge may differ between developed and developing economies, between times of surplus and times of shortage, and among differing production and marketing systems. Regardless of the specific situation, the essence of the marketing strategies suggested here is to focus first on the uses for which triticale has maximum achievable and demonstrable value, then over time to expand the area of overlap between triticale's capabilities and human needs. That expansion can be accomplished by developing new triticale varieties and production systems to meet those needs more effectively, and by helping producers and users discover and increase value from triticale. In that sense, marketing strategies identify and fulfil the most promising immediate opportunities, while shaping products and customer demand to create future opportunities. Triticale marketing encompasses marketing at many levels, from seeking funding for triticale research and development programmes, to selling seed or grain. Each level involves somewhat different marketing challenges, but success at each level is interrelated with success at the other levels, and success at all levels ultimately depends on the ability to demonstrate the competitive advantage of specific triticale products to meet specific needs.

TRITICALE CAPABILITIES AND MARKETING OPPORTUNITIES

Compared to other crops, the capabilities of triticale in general include higher yields of grain and forage with fewer production inputs and potentially less impact on the environment. As reported in other chapters, the needs that triticale can fulfil include grazing, ensilage, hay, grain for feed, food and industrial use, protection of soil from erosion and nutrient uptake to prevent water pollution. Because triticale fulfils such widespread and fundamental needs, its potential impact is far-reaching and its market potential is large. Described below are some of the advantages of triticale:

- Triticale is better than common wheat in the use of soil nutrients, stress tolerance, pest problems and benefits for soil and water quality. The shift of some hectares from common wheat to triticale will provide environmental benefits by improving nutrient management and reducing the need for pesticides.
- The local production and use of triticale grain for

feed provides producers with additional local marketing opportunities and can help recycle nutrients from animal-feeding operations.

- The superior protein quality and phosphorus digestibility of triticale grain can reduce nitrogen and phosphorus effluent from livestock.
- Triticale's superior root system and high biomass production, combined with its superior tolerance to lagoon water, make it an ideal crop for managing nitrogen and phosphorus from dairies and other animal-feeding operations.
- In addition to direct economic and environmental benefits, triticale also provides indirect benefits by diversifying the production environment and the mix of crops being marketed.
- Triticale pasture is more productive, more tolerant of stress and has a longer season than pastures of common wheat. Triticale in place of common wheat planted early for grazing could significantly reduce the build-up and spread of pests to surrounding late-planted wheat.
- Where common wheat is now used for both grain and forage, greater use of triticale for forage would allow wheat breeders and producers to focus more on the breeding, selection and management of common wheat for grain milling and less for forage. Similarly, triticale feed grain can satisfy the need for 'feed wheat' varieties bred for high yields, which are of interest to some producers in areas where common wheat grain is sometimes used for feed. By meeting the need for forage and feed grain, triticale favours the development and production of common wheat targetted specifically for milling and baking.

The marketing opportunities for a particular triticale programme depend on its products and overall resources and capabilities, and the obstacles it would face in pursuing the opportunities. Inevitably, resources are insufficient to pursue all of the marketing opportunities, so priorities must be established and effort and resources directed accordingly. Priorities can be set by rating the potential opportunities and the ability of the programme to fulfil each of them based on:

- product concept;
- product development capability;
- current products;
- protection of intellectual property;
- production;
- distribution;
- promotion; and
- sales.

Each of those aspects of the programme can be rated as being empowering (i.e. a key competitive advantage), adequate, inadequate, or uncertain. The assigned rating is based on the nature of the opportunity, the capabilities of the programme and the obstacles that the programme faces to fulfil the opportunity. A first step to prioritizing opportunities for the programme is rating the strength of the product concept for each of the marketing opportunities, identified by geographic region and end-use, for example. After addressing these questions about 'is it worthwhile to do', the question is 'can we do it' based on the product development capability of the programme in light of the obstacles it must overcome. The short-term answer to that question already may be known if the programme already has products for that marketing opportunity. Rating the strength of products already developed for that marketing opportunity is the key basis for establishing immediate marketing strategies and priorities. For rating both immediate and long-term opportunities, the protection of intellectual property (e.g. plant breeders' rights) is an overriding concern for any triticale programme that must sustain itself with revenue from the use of the products it develops. Triticale seed is easy to multiply and to use without authorization from the plant breeder or other owner of the variety. In some geographic areas, the high risk of violation of plant breeders' rights significantly limits the potential of marketing opportunities for triticale there. Finally, the rating of marketing opportunities depends on the capability of the programme to produce, distribute and promote the product, and especially on its ability to translate those capabilities into sales.

The general capabilities of triticale as a species may generate interest, but the success of a specific marketing programme depends on the particular strengths and benefits of the specific triticale products that the programme has to offer the market. The triticale crop species consists of a diverse collection of varieties and germplasm in terms of both agronomic characteristics and suitability for various uses. Each variety has its own combination of strengths and weaknesses concerning types of uses, tolerance to cold and pests, soil problems and other potentially limiting factors. A first step in marketing a triticale product is to inventory its features and benefits for specific uses. The tremendous diversity of capabilities and uses for triticale underscore the need for thorough, disciplined evaluation of which uses offer the most promising marketing opportunity for the specific triticale products that are being marketed.

PRODUCT DIFFERENTIATION

An important part of any marketing strategy is product differentiation, in this case establishing how a triticale product that is being marketed differs in a positive way from other crops and other triticale products. A useful approach for identifying potentially important points of differentiation is to focus on the criteria that are most important in customers' buying decisions and on the features of the product that could provide the most benefits as perceived by the customers. Triticale often competes with common wheat in the growers' decision about what to grow and for some end-use markets, such as forage and feed grain. In a generalized comparison between the two crop species, triticale has important advantages over common wheat, including higher yield potential in many environments, better resistance and/or tolerance to biotic and abiotic stresses and a higher concentration of essential amino acids, such as lysine, although current varieties of triticale are not as valuable as common wheat for large-scale, commercial bread making.

Of course the key comparison in practice is how a specific triticale variety compares with the best available wheat variety. Increasingly, as use of triticale increases, the marketing challenge becomes less one of differentiating triticale from other crops and more one of differentiating the specific triticale product from other triticale. In competing against both other crops and other triticale, key points of product differentiation in important markets in the United States of America include: (i) forage yield for pasture, silage and hay; (ii) tolerance to heavy grazing, pests and drought; (iii) high uptake of nitrogen and phosphorus for managing nutrients from animal-feeding operations; and (iv) yield of grain used for feed. In Brazil, the main point of differentiation of triticale from common wheat is its adaptation to acid soils (Mergoum *et al.*, 1998), while in North Africa and Australia, drought tolerance, disease resistance and high biological yields are the main points of product differentiation of triticale from other crops (Mergoum, Ryan and Shroyer, 1992). In other parts of the world, the key points of differentiation may be different, but in all cases the identification of those key points is an important part of developing a marketing strategy.

TRANSLATING BIOLOGICAL POTENTIAL INTO MARKET POTENTIAL

Of course the potential of a particular marketing opportunity depends on much more than just the biological or technical potential of a triticale product for a particular use and market area. Among the other factors that should be considered are the prospects for convincing potential customers about the benefits of the triticale product, the means of providing customers with the triticale product and information supporting its use and the ability of those marketing the triticale products to sustain financially their efforts serving the targetted marketing opportunity.

The use for triticale that has the largest potential area of production or the largest potential benefits in aggregate or per hectare may not be the most promising marketing opportunity. For example, triticale may have tremendous biological potential for the production of forage and grain but government subsides may favour the production of other cereals, or limited use of purchased certified seed may limit seed sales.

MARKET SEGMENTATION

The grain, forage and conservation uses for which triticale is well suited in many cases involve large, extensive markets encompassing large geographic areas and many producers and users. Attempts to market a triticale product over so large a market from the beginning of the marketing programme can spread the marketing resources and efforts too thinly to be effective. One approach to a large, extensive market is to identify and concentrate on small segments within it for which the triticale product is particularly valuable and for which the marketing programme is well placed and well suited. Along with product differentiation, this process of market segmentation is an important one in developing and implementing a marketing strategy. The smaller, more finely targetted segments of a market can serve as 'models of success' that are worthwhile in themselves and that can be used to document and exemplify benefits for subsequent marketing to other segments in the larger, overall market.

This process of targetting small segments of a larger market is simply an extension of the more general evaluation used to identify which uses offer the greatest immediate opportunity for the triticale products that are being marketed. The goal of the evaluation and targetting is to identify and pursue the specific marketing opportunities that can provide the best immediate results and generate momentum and validation for marketing to larger markets. For example, triticale has significant potential as a feed grain for swine and poultry in the Southeast United States of America (see section "Triticale grain for the Southeast"). Within that large region and type of use, triticale has especially great potential where production conditions are particularly favourable for triticale compared to competing crops and end-users are familiar with triticale and prepared to offer a favourable price for it. By concentrating on those areas that are particularly favourable for the production and sale of triticale grain, the marketing effort has the greatest chance of immediate success and a basis for later extending the marketing effort into other areas within the larger target market.

LARGE COMMODITY MARKETS AND SMALL NICHE MARKETS

For most users of triticale feed grain or forage, that grain or forage is simply a bundle of nutrients. The demand is not for the triticale feed grain or forage *per se*, rather the demand for the grain or forage is derived from demand for the feed energy, amino acids and other essential nutrients needed to produce the livestock product. The fact that, for some uses, triticale can be viewed as a bundle of the same feed nutrients for which there are already large, established markets is an advantage in that the marketer can tap existing demand and markets rather than having to develop demand and markets for a totally new product. On the other hand, the fact that demand for triticale reflects the underlying demand for the nutrient content of the triticale poses problems because triticale must compete with many substitute products that can provide the same nutrients. Most current uses for triticale, for example, are grazing, silage and hay, for which close substitutes are readily available. The availability and cost of those substitutes are important in determining interest and demand for a triticale product.

Similarly, on the supply side, farmers typically have other similar crops that they have been growing instead of triticale. The similarities between triticale and the other crops, such as common wheat, facilitate triticale marketing from the standpoint that farmers already have the knowledge and equipment needed to produce the crop; but at the same time, it constrains triticale marketing because of competition from the similar, substitute crops that the farmer could grow instead of triticale. The additional benefits to farmers from growing triticale instead of those competing crops must be large enough to motivate a change to triticale.

Marketers of triticale products for commodity markets for feed nutrients, for which there are many substitute sources, must evaluate the strength of their product compared to all those other sources, not only against other triticale products. A triticale product may be the best triticale available for meeting a specific need, but might still not be successful because other substitute products may be superior for meeting that need. A thorough, objective evaluation of the relative strengths of the triticale product compared to all possible substitutes is essential to understanding the marketability of the triticale product. Conducting this evaluation can be difficult for triticale marketers, many of whom have had to be “crop champions” with the vision, commitment and persistence to overcome the many obstacles faced in the establishment of a new crop such as triticale. The challenge is to be realistic and practical while retaining the passion and persistence needed to succeed.

For a triticale variety that yields substantially more with comparable inputs than a competing crop that produces a similar bundle of feed nutrients, the most easily developed markets in the short run may be those commodity-like feed nutrient markets because those markets are readily available if the price of the product is competitive for the buyer. In the long run, however, the most attractive markets for a triticale variety may be those for which the variety, or at least triticale in general, is uniquely suited and for which there are no close substitute products. One example is the use of triticale for food products that specify triticale on the label, or that depend on triticale for a unique product characteristic, such as flavour, health benefits, or simply novelty.

Demand for triticale for food use is currently very limited, but provides a stable, worthwhile niche for some producers. Because many varieties of triticale tend to have fewer significant pest problems and produce more for a given level of inputs than other competing crops, triticale may be a good option for organic production for food or feed use.

Another marketing opportunity for which triticale is differentiated from other products is for use in nutrient management plans for some dairies that specify that triticale be used to take up nitrogen and phosphorus and minimize the movement of those nutrients into surface water and groundwater. To comply with the required management plan, dairy producers must plant triticale rather than other competing crops.

These specialized uses for which triticale has unique benefits that differentiate it from other products are typically more difficult and time-consuming to develop and are small compared to the large commodity-type markets, but may provide more rewarding and stable returns in the long run.

A TRITICALE MARKETING CHAIN

The marketing of triticale occurs at multiple links in a chain that extends from genetics to the ultimate use of forage and grain. An individual marketer or organization may have products at only one single link, or may vertically integrate multiple links in that chain. For example, a triticale breeding organization may focus exclusively on developing varieties and then sell the rights to produce and market seed of those varieties to seed companies, or it may itself engage in the production and marketing of seed and perhaps even grain of the varieties it develops. Even if they do not directly participate in marketing at more than one link in the chain, every marketer of triticale should be attuned to production and marketing at the other links.

A production or marketing problem at any link in the chain can disrupt marketing at all the other links. The importance to marketers at any one link to what is happening at the other links is even greater for triticale than it is for other crops, such as wheat, because the marketing chains for the other crops are already well established. The greater importance of knowledge about the entire marketing chain, and possible need to participate at other links in that chain, adds to the challenges of triticale marketing and is an important distinguishing feature of triticale marketing compared to the marketing of wheat and other well-established crops.

A useful tool for analysing a triticale marketing chain is a role chart that lists all the links and all the roles that must be filled to put each link in place (Table 1). The role chart highlights the fact that the marketing of triticale encompasses the marketing of many different types of products, from genetics to food, each with its own set of potential customers and buying criteria. Each link in the chain entails:

- financing to cover cost;
- management to guide completion of the link; and
- the actual performance of the work involved.

All three roles at a link might be performed by one organization or they may be divided among multiple organizations.

The role chart can be used by an individual marketing organization to map out its own position along the chain and to map out the positions of other organizations that compete with it or perform complementary roles. Charting which organizations perform which roles may reveal weak links that must be strengthened, or suggest where alliances could be formed to strengthen the overall chain. One organization may provide multiple links, which need not be consecutive. For example, an organization that is strong financially and strong in the contracting and handling of triticale grain may be well positioned also to finance and handle the production of triticale seed. Unlike other crops for which the handling of seed is quite unlike the handling of the ultimate crop produced from that seed, the bulkiness of triticale seed, and consequently the large amount of seed needed for planting per unit area, may favour a marketing chain in which organizations that handle grain also handle seed, especially if the organizations are contracting the production of grain by the grower customers who purchase the seed.

In addition to being important because success at any one link depends on success at the others, the way marketing is conducted at one link may directly affect how it is done at another link. In fact, measures taken at one link can solve problems at another link that would be difficult to solve at that link in isolation. For example, ‘closed loop’ programmes in which seed is only sold to farmers who are part of a cooperative effort to produce and market grain can help coordinate grain supply and demand to the benefit of both farmers and grain users as well as deter illegal seed production and sales. More generally, integrating activities and products across multiple links to produce an overall system solution, a package of products and services, can enhance the value of each product and service to the ultimate customer and thereby contribute to success at all links.

Triticale genetics and seed are an integral part of most triticale marketing efforts at this point in the development of the crop. Although not specific to triticale, Johnson Douglas’ book on the planning and management of seed programmes provides useful guidelines for successfully promoting the use of seed of improved varieties (Douglas, 1980). These guidelines are targetted primarily for seed programmes in developing countries.

In addition to the marketing that occurs at each of the links in the chain, triticale marketing also encompasses the overall marketing of triticale as a crop in a more general sense. Efforts to raise awareness about triticale in general and the benefits it can provide are important for all those involved with triticale at any link in the chain because it strengthens demand for the crop at all links. Policymakers in particular may be the focus of, or themselves focus on, the general marketing of triticale as a crop, for example, for addressing issues related to subsidies that favour other crops over triticale.

Another potentially important audience for triticale marketing is organizations that provide products or services that are potentially complementary with triticale. For example, the producers of crystalline amino acids, which together with triticale grain can totally replace soybean meal in some livestock diets, could be potential

TABLE 1
Example role chart for a triticale grain programme

Activity	Who performs?	Who manages?	Who finances?
Identify customer needs and product opportunities			
Develop, release and protect crop varieties to meet needs and fulfil opportunities			
Demonstrate the benefits of the product to growers and grain users			
Develop and communicate information to motivate and instruct sales representatives, customers and influencers			
Affirm commitment from grain users to buy triticale grain at a predictable price; obtain contract from grain users			
Assess demand and set production area target			
Produce, process, assure quality of, store and manage parent seed			
Produce, process, assure quality of, store and manage commercial seed			
Make seed conveniently available in desired form			
Manage unsold inventory			
Reiterate and individualize benefits of product offering to grower customers			
Obtain signed production contracts from growers			
Deliver seed and collect payment			
Provide technical support for optimal product use			
Receive grain			
Pay growers or if a marketing pool, manage records and inventory for future payment			
Store, transport and analyse grain as needed to fulfil grain buyers' specifications			
Collect payment from grain buyers			
Follow up with grain growers and users to reinforce benefits and refine programme			

allies in the development of markets for triticale grain.

For each marketer, the interdependencies among links of the marketing chain and the benefits of effective coordination among those links add to the importance of developing good working relationships with the people involved at those other links.

CREATING NEW MARKETING OPPORTUNITIES FOR TRITICALE

This discussion of triticale marketing strategies has emphasized the role of marketing in identifying and fulfilling the current potential of triticale. Marketing strategies also have important roles to play in developing new triticale varieties and in creating new marketing opportunities. Marketers can assist triticale breeders by identifying and prioritizing marketing opportunities, for example, by elucidating the combinations of grain yield and quality that provide the highest value of feed grain production per hectare. Marketers can create new opportunities by encouraging changes in agricultural production that favour triticale, for example, by encouraging greater reliance on cool-season cereal forage such as triticale as a means to reduce water use and environmental impact while still achieving high yields of high-quality forage.

Whether fulfilling current opportunities or creating new ones for the future, marketers of triticale are fortunate in that triticale has the potential to fulfil a diverse range of fundamental needs across a wide range of production environments. To the extent that triticale can fulfil those fundamental needs more effectively and efficiently than other products, there will always be markets for triticale regardless of whether the emphasis at the time is on productivity, costs of production, or environmental impact. Marketing strategies that match triticale varieties with the needs for which they are the best solution create a solid, sustainable base for the development of triticale into a major crop.

In summary, the key aspects of strategies for marketing triticale include:

- Identify the features and potential benefits of the specific triticale product (i.e. the crop capabilities) that differentiate it from other crops and other triticale products.
- Identify and focus on the uses and customers (the segments of the market) for which those features and benefits are particularly valuable (i.e. find the strongest match between crop capabilities and customer needs).
- Assess the ability of the marketing programme to reach those potential customers with the marketing message and then with the product and to obtain the payback needed to sustain the programme.
- Among the customers for whom the triticale product has value, focus marketing efforts first on specific market areas and customers that are readily accessible by the marketing programme, which would serve as influential models of success.
- For those models of success, and ultimately for the broader marketing effort, individually, or in cooperation with others, forge all links in the marketing chain that extends from the breeding of triticale varieties, to seed, to end products and finally to the ultimate user of the triticale product. Strive to have each link performed by those most effective and efficient at performing it so that the overall chain creates maximum net benefits for customers and for those performing the necessary roles.
- Build the programme by demonstrating, documenting and communicating the benefits provided to customers by the product and by preventing unauthorized use of the product.
- In addition to the marketing of specific triticale products, promote triticale in general as a crop that deserves consideration and equitable treatment by policymakers, regulatory and funding agencies and producers of complementary products that enhance the production or use of triticale.
- Expand markets by improving triticale varieties and systems of use and by helping producers and users discover and increase value from triticale.

A CASE STUDY: TRITICALE MARKETING STRATEGIES IN THE UNITED STATES OF AMERICA

An important feature of the marketing strategies exemplified in the following case study is the importance placed on building linkages along the complete marketing chain from genetics to end-users. Communication, coordination and building of strong relationships are key to building those linkages. Enough value must be created, preserved and shared to assure that participants at all links in the chain are adequately repaid for the roles they play. Prospects for doing so are best if each role is performed by those who are the most efficient and effective at performing that role and if those different roles are coordinated to enhance the overall efficiency and effectiveness of the entire chain.

Triticale forage markets

Forage markets have proven to be good starting points for the commercial development of triticale in the United States of America. In most cases, in those markets the grower of the triticale is also the user of the product produced, so the marketing chain is shorter and the coordination of supply and demand is much less of an issue than where different producers and users must be brought together to create a market. The use of triticale for grazing in the Southern Plains of the United States of America is the oldest and largest market for triticale forage in the United States of America (Fohner, 1990).

Triticale for the Southern Plains

The match between triticale and critical needs

Wheat and beef cattle are mainstays of the farm economy in the Southern Plains. Wheat is the region's primary crop in terms of area and total value. In addition to the value of the grain it produces, wheat pasture contributes significantly to the region's beef production. In recent years, wheat pasture has become increasingly important economically relative to wheat grain. Even as a grain crop, the value of wheat is linked to the livestock industries because in many years a large proportion of the wheat grain is used for feed grain.

Triticale has important advantages over wheat for pasture, hay and feed grain (Table 2). Insects, diseases and limited moisture are major constraints on the use of wheat for pasture. The superior tolerance of triticale to these constraints allows earlier planting, extended grazing and higher forage production. These tolerances also contribute to higher grain yields in triticale.

The opportunity and need for triticale are increasing as government farm programmes become more flexible and less sufficient for maintaining farm income. The need is particularly great for dryland farms and for irrigated farms facing restricted availability and higher cost of water. As a complement to wheat, triticale can contribute significantly to the profitability of agriculture in the Southern Plains. A market study conducted in 1995 gauged the potential opportunities for triticale in that region (Resource Seeds, 1995).

TABLE 2
Potential of triticale to satisfy critical needs in the Southern Plains

Critical needs of agriculture in the Southern Plains
• More productive, longer duration pasture for beef cattle
• Profitable crops for dryland farms
• Profitable crops that require less water than maize or alfalfa for water-restricted, irrigated farms
Key features of triticale for forage in the Southern Plains
• Higher forage yields than wheat or rye
• Not a weedy contaminant like rye or ryegrass
• Better adapted than wheat for early planting and autumn grazing
• Longer grazing in the spring than wheat or rye
• Superior tolerance to drought, pests and low pH
Key features of triticale for grain in the Southern Plains
• Higher grain yields than wheat or rye
• Lower production costs and water requirements than maize
• Higher protein content and quality than maize
• Higher feed value and profit potential than sorghum

Forage area

Although a dual role as both a forage and feed grain is the eventual goal for triticale in the Southern Plains, grazing is its most immediate opportunity. Even without including 'permanent' pasture, over 12 million ha of cropland are used for forage production in the three 'core' states of the Southern Plains: Kansas, Oklahoma and Texas. Of this, approximately 4.8 million ha are small-grain pasture and hay, of which about 90 percent is wheat and 10 percent is triticale, oats, rye and barley. More than 4.5 million ha of the small-grain total is used for pasture (Bureau of the Census, 1994).

Wheat pasture and graze out

Most wheat used for pasture is also harvested for grain. However, depending on growing conditions and the prices of wheat and cattle, some wheat hectares are used only for grazing and are not harvested for grain. The number of these 'grazed-out' hectares varies from year to year. In 1992, a typical year, 1.5 million ha of wheat in the Southern Plains were grazed out, used only for pasture and not harvested for grain. These 1.5 million ha are a primary target for triticale (Resource Seeds, 1995).

Wheat area on livestock farms

Further segmenting the market using data from the 1992 United States of America Census of Agriculture, the market study conducted in 1995 obtained additional insights (Resource Seeds, 1995). In addition to the 1.5 million ha of wheat grazed out, another 2.1 million ha were grown on farms for which beef cattle was the primary source of income. Combined, the grazed-out hectares and wheat grown on farms where livestock is the primary enterprise, these two market segments represent about 3.6 million ha of wheat oriented around livestock production and positioned to capture directly the maximum economic benefits of triticale through the combination of crop and livestock enterprises.

Cattle ownership by cash grain farms

The opportunity for maximum benefits from triticale are not confined to livestock farms, however. In some parts of the Southern Plains, especially Kansas, a significant proportion of stocker cattle are owned by farms for which cash grain is the primary source of income (Bureau of the Census, 1994). Similar to livestock farms that have significant wheat area, crop farms that have significant stocker herds can directly capture the maximum benefits of triticale.

Positioning triticale for current marketing opportunities

In the future, changes in government farm programmes and improved baking quality of triticale may make triticale a more direct substitute for wheat in the Southern Plains. For now, however, triticale is best viewed for that region as a complement to wheat as part of whole-farm 'graze and grain' programmes for crop and cattle production (Table 3).

To provide pasture, approximately half of the wheat hectares in the Southern Plains are planted earlier than is optimal for grain production. Early planting of wheat has two major drawbacks: (i) early-planted wheat generally yields far less grain than later-planted wheat, up to 50 percent less in research by Texas A & M University (Winter, 1994); and (ii) early-planted wheat becomes a source of diseases and insects that spread to surrounding wheat and reduce its productivity (Sears, undated). Consequently, early-planted wheat can reduce yield on surrounding, later-planted fields in addition to having lower yield itself (Sears, undated).

Triticale is an ideal replacement for early-planted wheat because of its superior forage production and greater resistance to diseases and insects. That resistance minimizes yield losses and avoids the build-up of pests that would spread to surrounding fields. Triticale performs well even when planted earlier than is common for early-planted wheat.

In addition to early-season benefits, triticale provides important late-season benefits. Triticale provides substantially more forage in the spring than does wheat in terms of both amount and duration. The greater production from triticale pasture can reduce spring grazing pressure on the farm's wheat hectares so those wheat hectares can be managed more favourably for grain yield while the farm's forage production and cattle gains are maintained.

Triticale can increase farm profitability directly as a more productive source of forage and feed grain and indirectly by helping improve the management and health of wheat on the rest of the farm. Wheat varieties can be chosen and managed with greater emphasis on grain production. In that respect, triticale is a particularly valuable complement to value-added wheats in the Southern Plains, such as white and high-protein varieties.

TABLE 3

Strategic framework for marketing triticale in the Southern Plains

Description
• A comprehensive management programme for optimal use of wheat, triticale and stocker cattle
Objective
• Maximize net farm income from cash grain and livestock enterprises
Programme highlights
• Early planting of triticale on areas that would otherwise be early wheat planted for grazing
• Later planting of wheat to avoid stress and pests and to increase grain yields
• Wheat variety chosen and managed with greater emphasis on grain yield and value
• Earlier, heavier grazing of triticale in the autumn; light winter grazing of wheat
• In spring, concentration of cattle on triticale
• Longer graze-out season on triticale than is possible with wheat
Variations in programme
• Graze out triticale
• Instead of grazing out triticale, harvest it for hay or feed grain
• Grow a dual-purpose triticale variety that has been developed for grazing and subsequent harvest for grain
Benefits of triticale in the programme
• Earlier autumn grazing
• More forage production per unit area
• Avoids build-up of insects and diseases on early-planted wheat
• Increase in wheat grain yield per unit area while enhancing farm's stocker cattle programme
• Extended grazing season to increase production and widen marketing window
• Graze out or take advantage of the significantly higher grain or hay yields of triticale compared to wheat or rye

Economic benefits of triticale

Partial budget analysis – comparing differences in gross revenue adjusted for differences in production expenses – indicates that in livestock-producing areas in the Southern Plains triticale is more profitable than wheat on hectares not receiving government deficiency payments. For both irrigated and dryland production, triticale provided substantially higher net income than wheat from graze out or a combination of grazing and grain harvest. Primarily as a result of its greater forage productivity, on average triticale had a per hectare advantage in dryland and irrigated production of US$62 and US$133, respectively, over wheat planted in early September and US$82 and US$168, respectively, over wheat planted in late September (Resource Seeds, 1995).

Although seed cost per hectare is typically higher for triticale than for wheat, its payback for farmers was over four times that added cost.

The economic benefits of triticale are also pronounced when analysed within the context of a 'representative' farm having 259 ha used for a combination of grazing and grain production. As a replacement for early-planted wheat, triticale provides higher income than the early-planted wheat it replaces and reduces the incidence of insect and disease on the farm's other wheat hectares. Consequently, net farm income is increased by higher yields from the other wheat on the farm in addition to the higher income from the triticale itself. In the analysis, the combination of direct and indirect benefits resulted in increased net farm income for dryland and irrigated farms from US$74 to US$232 per hectare of triticale on the farm (Resource Seeds, 1995).

Obstacles to successful triticale programmes

Two obstacles have limited the success of triticale programmes in the Southern Plains. The first obstacle is United States government loan and insurance programmes that favour common wheat over triticale. These loan and insurance subsidies available for wheat but not triticale discourage the planting of triticale throughout the United States of America. The second obstacle does not limit the planting of triticale directly, but has greatly limited investment in the development of triticale varieties and programmes for the Southern Plains. This obstacle is the frequent violation of plant breeders' rights in the region and the low percentage of triticale and wheat hectares planted with certified seed or even professionally produced seed. Low use of purchased certified seed has also been cited as a problem for triticale breeding programmes in Europe (Arseniuk and Oleksiak, 2002; Weissmann and Weissmann, 2002).

The ideal measures to protect plant breeders' rights are ones that also increase yield. For example, blends of multiple triticale varieties that have complementary growth habits can be superior to any single variety in terms of the duration, total quantity and reliability of pasture production. These blends also discourage unauthorized seed use and violations of breeders' rights because they tend to be difficult to harvest and manage for seed production and because the component varieties rarely produce seed in proportion to their percentage in the original blend.

The development of hybrid triticale would increase yield as well as limit the use of unauthorized seed. The significant heterosis found for yield and the prolific pollen dispersal and extended receptivity found among triticale varieties suggest that hybrid triticale could provide substantial benefits for farmers and could be economically feasible to produce with the systems of cytoplasmic male sterility (CMS) and other approaches now being developed (Warzecha and Salak-Warzecha, 2002; Burger, Oettler and Melchinger, 2002). For some markets, such as the grazing market in the Southern Plains, even the use of hybrids may not deter unauthorized use and illegal sale of seed. When hybrid wheat was marketed into that region in the 1990s, widespread harvest and planting of F_2 seed (i.e. seed harvested from the hybrid plants) was reported for some areas where grazing was the primary use.

This pattern of seed use reflects other underlying obstacles to triticale marketing in the Southern Plains. These obstacles include the high risk of crop loss and low economic returns for farming in many parts of the Southern Plains and a traditional aversion to any constraints on the free use of farmer-saved and locally traded seed. Some estimates are that the certified seed is used on less than 5 percent of the wheat area in the state of Texas, which is a primary target market for triticale in the Southern Plains. Wheat, triticale and other small grains are typically planted in the Southern Plains with seed saved on the farm, sold among farmers, or sold by unauthorized seed cleaners who do not pay the plant breeder for use of the variety. Despite these two significant obstacles, triticale area continues to increase in the Southern Plains, and a small number of private and public breeding programmes continue to provide varieties for production there.

Triticale for dairy ensilage

Another forage market that has become a good market for triticale is the market for dairy ensilage in the western part of the United States of America, where most of the growth in the country's dairy production is occurring. Critical issues for the dairy industry in the western United States of America include nutrient management, availability and cost of water and cost of forages. Varieties of triticale adapted for forage production in that region are providing high yields of high-quality forage, while helping manage nitrogen and phosphorus in the dairy effluent and requiring less water for production than most other forages (Table 4). The triticale dairy silage crop is typically planted in the autumn and harvested in the spring in combination with a summer annual forage, such as maize silage. In the most productive, long-season areas,

TABLE 4
Features and benefits of triticale forage

Features	Benefits
Annual growth habit	Quick source of forage Quick payback on production costs Flexible in crop rotations Fast response to changing economic and production conditions
Cool-season crop	Efficient use of soil moisture Less vulnerable to drought Double crop with warm-season crops Complements warm-season crops in terms of workload, production inputs and feed supply Reduces soil erosion Aids management of nitrogen and manure during the cool season; utilizes nitrogen and prevents run-off and percolation into groundwater
High biomass production	High return of forage and income per hectare and per unit of other inputs
Many potential uses	High potential uptake of nitrogen and phosphorus Versatile source of products for a variety of needs: vegetative or boot stage for high-quality forage post-boot stage for high yields of intermediate-quality forage grazing grain and straw
Deep-rooted and efficient uptake of nutrients from the soil	High yields per unit of available soil nutrients High potential uptake of nitrogen and phosphorus from throughout the soil profile
Competitive with weeds	Minimizes costs, regulatory requirements and undesirable effects of herbicides Helps control weeds that affect other crops in the rotation Helps establish new stands of alfalfa and enhances declining stands with interseeding
Relatively few economic pests	Minimizes costs, regulatory requirements and undesirable effects of pesticides Low risk of major crop loss to pests if crop variety is chosen prudently
Widely adapted	Wide range of varieties allows production under diverse conditions
Low input requirements	Low input cost and financial risk Equipment required is modest and usually already owned for other enterprises
Provides rotational benefits	Helps control pests that affect other crops in the rotation, reducing production costs and increasing yields

that double-crop combination can provide approximately 35 tonnes of forage dry matter per hectare.

For introducing triticale forage into a dairy area, marketing can begin by focussing on the current use of other small-grain cereals for forage. In the past, in the western United States of America, for example, wheat and oats have been the most widely grown small grains for dairy forage. The first step in marketing triticale into that dairy market has been in competition with wheat silage because of the similarities between the two crops, which aids the substitution of one with the other. The recent availability of awnless or 'beardless' triticale will facilitate the substitution of triticale for oats for hay production and thereby strengthen another immediate marketing opportunity.

While focussing on the immediate opportunities to substitute triticale in place of other small-grain cereal forages, marketing strategies should also provide for long-term opportunities to substitute triticale for other forages in production fields and dairy rations. Fulfilling those opportunities requires convincing dairy nutritionists and other key 'influencers' that triticale forage will be a good substitute, a task complicated by the fact that the nutritional attributes of triticale forage, as with all other small-grain cereal forages, depend greatly on the growth stage at which the crop is harvested (Cherney and Marten, 1982). Also, past use of unsuitable varieties and poorly timed harvests have given some nutritionists in the western United States of America the impression that triticale does not provide high-quality forage. The task of demonstrating the benefits of triticale forage for dairy feed is further complicated by the fact that some measures of forage quality, such as neutral detergent fibre (NDF) and acid detergent fibre (ADF), are poor predictors of digestibility and energy value of small-grain forages (Resource Seeds, 1998; Fohner, Shultz and Aksland, 1994). Documenting forage quality and communicating results to dairy nutritionists and others who influence forage production and feeding systems are key parts of marketing strategies to expand the use of triticale forage. Eventually, in addition to displacing other small grains, the economic and environmental benefits of triticale will offer marketing opportunities to increase the use of triticale in the place of other forage crops.

Triticale grain markets

Grain markets have proven to be difficult to develop for triticale in the United States of America. In the last few years, however, the availability of higher yielding varieties and the increased importance of environmental issues have renewed interest in grain triticale in several parts of the country. Three case studies exemplify the marketing strategies that have emerged from this renewed interest, two from the Pacific Northwest and one from the Southeast United States of America.

Triticale grain for the Pacific Northwest

Marketing group I

One effort to develop and serve markets for triticale grain in the region began with university research that demonstrated that two new varieties of triticale developed in Europe produced substantially higher grain yield than common wheat or previously available triticale (Karow and Marx, 1999). The magnitude of the yield advantage suggested that growers in at least some parts of the region could increase income by switching from common wheat to triticale. Previous efforts to develop grain markets for triticale in the region had been hampered by a lack of coordination between producers and users of the grain. Producers were hesitant to grow triticale grain until they were confident that there were buyers for the grain who would pay a satisfactory price. Users of feed grain were reluctant to commit to purchasing triticale grain or to specifying a price until they were confident that supply would be adequate to justify changing to triticale and until they assessed the value of the triticale grain for meeting their needs. The availability of the new, higher yielding varieties provided stronger incentive and renewed interest in trying to bring supply and demand together to form a market for triticale grain.

The institution with rights over the two varieties sought participation from other companies and organizations that together could fulfil all the necessary roles in the marketing chain from genetics to use of grain. Decisions about how to fulfil those roles were influenced by four key considerations: (i) access to the genetics; (ii) coordinating supply and demand; (iii) assurances for grain growers and users; and (iv) maximizing value of the crop.

In light of these considerations, the institution with rights to the two varieties formalized and solidified arrangements with two other organizations to form the core of the marketing effort. Of these two, the first organization was the university group that first demonstrated the potential of the two triticale varieties for growers in the region. In addition to doing excellent research to further document the performance and potential of the triticale varieties, the reputation and communication capabilities of the group was ideal for helping to present the opportunity to growers. The second organization was an agricultural marketing company that markets agricultural inputs, including seed, fertilizer and chemicals, to farmers and also purchases and sells products, such as grain and hay, from farms. This company spanned several links in the marketing chain and could internally coordinate production and marketing of triticale grain.

With the participation of the three organizations, the following programme was implemented:

- The marketing company develops markets and creates demand for grain of the two varieties. Prior to planting time, the company assesses the level of demand for the grain and establishes production targets. Subject to those targets and seed availability, seed of the two varieties is sold to any grower in the region who agrees to use the seed in accordance with the production agreement, which stipulates that the grower will market through the marketing programme all the grain of the two varieties produced under the terms of a signed pre-plant production contract with the marketing company. In addition to paying the grower for the grain, the marketing company is responsible for the cost of operating the marketing programme, for payments due to the grain commission and for additional research assessment and market development costs. Alternatively, with prior arrangements with the marketing company, the grower may use the grain for on-farm feeding or for transfer to a neighbour for feeding. The marketing company does its best to accommodate individual situations. The primary approach for on-farm or local use arranged by the grower is for the grower to repurchase some or all of the grain from the marketing company. To repurchase grain, the grower must warrant in the agreement with the marketing company that the grain will be used to feed livestock on his or her farm or on those of neighbours. All grain is weighed and subject to audit regardless of whether or not it is repurchased. One last variation on possible use of the crop would be if the grower elects to harvest the crop for forage instead of grain, then a nominal fee specified in the grain production contract may be charged at the discretion of the marketing company for voiding the grain production contract.

- Seed is sold to growers at a price comparable to proprietary wheat seed and without being tied to the purchase of other production inputs from the marketing company.
- The price paid to the grower by the marketing programme for the grain is based on a price formula that reflects the value of the grain relative to competing grains as determined in research studies and commercial use. The production contract signed prior to seed sale and planting specifies the method that will be used to set the payment price at the time grain is sold to the marketing company for marketing. The marketing programme strives to assist growers who would like to 'lock in' a fixed contract price prior to harvest and delivery, either directly or by providing information that would help them and their advisors hedge prices.

Briefly, the basic structure of the programme is that the marketing company: (i) contracts seed production with growers in the region; (ii) develops and arranges to supply grain users with the triticale grain; and then (iii) sells seed and contracts grain production of the two varieties with growers in the region to match the demand that the marketing company has generated from grain users. To assure reliable markets for producers, reliable supply for grain users and observance of property rights, seed is only available to growers who participate in the marketing programme or who coordinate their own use of the grain with the marketing programme, thereby creating a 'closed loop' between the seed and grain.

Marketing group II

A different approach to marketing triticale grain was taken by a second group located in a different part of the same region targetted by group I. The group had the same objectives and overriding considerations, but took a different approach reflecting the differences in its strengths compared to those of the organizations in the first marketing group. This second group was led by a company that specializes in applied research and market development. This development company had access to the most promising triticale varieties in the region, the facilities and know-how to multiply and process parent seed stocks and the capability to do small-plot and large-scale testing and demonstration of the varieties. It lacked the financial resources or infrastructure to contract production and handle or manage inventories of large quantities of seed or grain.

The development company sponsored research to quantify the value of the triticale grain for swine and poultry producers in the area, then developed relationships with those buyers to obtain their commitment to buy the grain at a price determined by the research studies and by the lysine content of the grain being sold. To complete a marketing chain from the genetics, to which it had access, all the way through to the end-users of the grain, the development company organized a pool of grain growers who were interested in producing triticale grain and in helping to support financially the marketing of that grain to end-users in their area. The development company also organized a group of grain handlers who wanted to participate in the storage and handling of the grain. Similar to the marketing company in the group I programme, the development company in group II gauged how much grain could be sold to the swine and poultry companies that would use the product, then sought to match that with production from the grower pool. The development company sold seed to the growers either directly or indirectly through the grain handlers who got the seed from the development company, or who were licensed to produce their own. The grain produced by the growers went into storage, was analysed for crude protein and lysine and then was supplied to the swine and poultry producer as requested at a price determined by the lysine content and the prices of alternative feeds at the time of the sale. For the large buyers, price was typically determined by a linear programming model and the matrix of prices of alternative feeds available at that time to the buyer. For some buyers, price was determined with a formula based simply on the price of maize and soybean meal, which are the dominant feeds in the area.

As in the marketing programme conducted by group I, seed of the triticale grain varieties sold by group II was only sold to growers who signed contracts to sell all the grain back to the marketing programme, or who obtained approval from the programme to feed it on-farm or to sell it elsewhere. Coordinating seed sales with grain production contracts helps keep supply and demand in balance at a price that is profitable for growers and competitive for grain users and deters unauthorized use of the varieties, which would deprive the breeders and seed suppliers of revenue needed to support their efforts.

Triticale grain for the Southeast

Several factors favour the development of triticale grain as a feed crop in the Southeast United States of America. Firstly, triticale is grown in the area for forage, and small quantities have been grown for grain in the past. Although previous varieties have not yielded enough to motivate large-scale production for grain, growers and livestock producers are familiar with the crop and supportive of efforts to develop its potential. In addition to there being a history of commercial acceptance of triticale in the Southeast United States of America, triticale is of interest to university researchers and others in the region who conduct research and demonstrations. The potential for supporting triticale breeding with commercial seed sales in the Southeast appears to be adequate. Although seed prices tend to be low, use of professionally produced certified seed of wheat and triticale is fairly high. An important indicator of the potential for triticale grain in the region is the fact that in many years the price at harvest of the soft red wheat grown in the Southeast is typically very close to the price of maize, and a large proportion of the wheat crop grown in the area is used for feed. Triticale varieties that have higher grain yield than wheat would have a higher market value per hectare than the wheat sold in the same feed market, although this yield advantage can be overshadowed by government subsidies for wheat and by growers' reluctance to plant triticale and forgo any chance at occasional high wheat prices for food use. In the competition between triticale and wheat in the Southeast, the triticale varieties have been favoured by their resistance to powdery mildew, which lowers risk of crop loss and the need for fungicides, compared to the susceptibility of most of the wheat varieties. Barley grain production in the region is minimal, but offers another potential market niche where triticale grain could get started.

The Southeast is a leading production region for swine and poultry, and as a region does not produce nearly enough feed to meet the needs of that livestock industry. The livestock producers, and in particular the swine producers, have had excellent results feeding triticale grain. The presence of a large, receptive livestock industry in a feed-deficit area offers a significant opportunity for triticale grain.

One of the most important factors currently stimulating interest in triticale in the Southeast is the environmental problem associated with the large livestock industry in the region. Each year, millions of tonnes of maize and soybean meal are shipped into the Southeast for feed. A significant portion of the nitrogen and phosphorus in that feed ends up in the effluent from animal feeding operations, thereby creating a major environmental problem for the region. Triticale is already being used as a forage crop to help manage effluent and to minimize the movement of nitrogen and phosphorus into streams. Use of locally grown triticale grain as feed would reduce the amount of feed that needs to be brought in from other regions and in effect would recycle livestock effluent back into feed, thereby helping to improve the overall nutrient budget of the region. Use of triticale instead of maize can substantially reduce the amount of phosphorus effluent from feeding operations because of the significantly higher bio-availability of the phosphorus in triticale grain compared to maize. The higher bio-availability results in more efficient use and less excretion of the phosphorus by the animal. Use of triticale grain supplemented with lysine and threonine amino acids can replace soybean meal as well as maize in the ration, producing equally good animal weight gains and meat quality as the maize-soybean ration while reducing the amount of nitrogen excreted from the animal by over 25 percent.

Within this generally favourable environment for triticale grain production, the triticale breeding company that targetted the Southeast for triticale grain developed a strategy that sought to build on the feed and environmental needs of the region and on the interest in triticale among university researchers and the commercial sector (Table 5). The strategy emphasized the benefits of triticale for the growers, livestock producers and those charged with implementing solutions to the environmental challenges of the region.

After identifying the potential benefits of triticale and its place within the region's agriculture, the marketing strategy entailed identifying and involving the organizations needed to fulfil all the roles of the marketing chain. Universities in the region have played a significant role from the beginning by conducting yield trials that document the superior performance of the triticale varieties, feed quality analyses and feeding studies to document feed value and refine feed use, and nutrient management studies to document and refine the use of triticale to improve the use of nitrogen and phosphorus.

TABLE 5
Strategic framework for marketing triticale grain in the Southeast

Critical needs of agriculture in the Southeast
• Profitable crops, especially where soil conditions, frequent summer drought, disease or other factors limit the profitability of wheat and maize
• Management of nutrients in effluent from animal feeding operations to minimize environmental impact
Description of feed grain and nutrient management programme
• Production of triticale feed grain and straw where soil conditions, climate or management practices favour higher net profit from triticale than from wheat or maize
• Use of triticale feed grain to reduce cost of grain in swine and poultry production, reduce phosphorus effluent and in combination with crystalline amino acids reduce nitrogen effluent
• Use of triticale straw for poultry bedding material
Objective
• Increase net income of crop and livestock producers and reduce phosphorus and nitrogen effluent
Crop production highlights
• Grow triticale as part of an annual rotation or double crop with soybeans where light soil, disease or late planting limit wheat yields
• Grow triticale on some hectares in high wheat yield areas for diversification in order to take advantage of superior triticale yields in years when wheat does not command large premiums over maize or triticale
• Grow triticale where soil or climate make maize an expensive, risky choice
• Reduce the cost and environmental impact of crop production by taking advantage of the higher disease tolerance of triticale compared to wheat
Feed use highlights
• Take advantage of the superior amino acid content and profile of triticale compared to maize and wheat to reduce soybean meal requirements and feed cost for swine and poultry
• Achieve further reductions or total replacement of soybean meal to reduce nitrogen effluent and feed costs by using crystalline amino acids with triticale to match the amino acid content of the feed more exactly to the nutritional requirements of the swine and poultry
• Take advantage of the higher phosphorus content and bio-availability of triticale compared to maize to reduce feed cost and phosphorus effluent
• Reduce the total net influx of nitrogen and phosphorus into the farm and region by increasing the use of locally produced feed
Straw for bedding
• Increase income from crop production by selling straw
• Harvest and sell straw to remove more nitrogen and phosphorus from cropland where they are excessive
• Alleviate the shortage of bedding material with locally produced triticale straw
• Use straw-based poultry litter as cattle feed
Variations in programme
• Instead of growing triticale for grain, graze it or harvest it for silage or hay
• In addition to using triticale as a milled feed, experiment with the practice of adding whole-grain kernels to poultry feed. Add 10 to 30 percent whole-grain triticale kernels to poultry feed to fine-tune protein density of the feed as birds grow and to improve animal health and gizzard function, which can improve gut development and protein digestion and reduce nitrogen excretion and wet litter. Improved structural development of the gut from whole grains may reduce tearing during processing and the risk of bacterial contamination as part of an integrated grower-to-processor Hazard Analysis Critical Control Point (HACCP) programme. Feeding of whole-grain triticale can reduce feed cost by reducing milling costs per tonne of finished feed

Based on the work of the university, the breeding company initiated pilot production with progressive farmers and supplied grain to livestock producers for evaluation. While these steps were taken to generate interest among growers and users of grain, seed companies were approached about production and distribution of seed.

In one area, the company approached about seed production and distribution had experience in contracting the production of grain and supplying it 'identity preserved' to end-users who sought that particular product. This company was capable of performing several roles at both the seed and grain links in the marketing chain, encompassing the production and distribution of the seed and the purchase of the grain to be supplied to the end-users.

In a second area within the Southeast, the company approached about seed production was the leading supplier of seed to the area, but was not involved with the grain. To provide the link between the growers and users of the triticale grain, the breeding company approached a prominent grain broker who handles grain produced by a large group of leading growers in the targetted area. The role of that broker was first to assess the information supplied by the breeding company about the yield potential of the triticale varieties and about the demand from specific livestock operations for the grain. Based on that assessment, the broker arranged for seed to be delivered to the growers and then merchandised the grain produced by the growers to livestock companies. The involvement of the well-respected broker reassures growers about the overall triticale programme, reliability of markets and payment for the grain they produce and provides the expertise and resources needed to supply the grain to the livestock companies reliably, conveniently and efficiently.

In both areas in the Southeast, the breeding company began at the two ends of the marketing chain: developing superior varieties at one end and securing commitments from livestock companies to purchase the grain at the other end. A key part of developing superior varieties is documenting and communicating that superiority with the help of university researchers and others who are credible third parties. A key part of gaining a commitment from livestock companies to buy triticale grain is to establish the basis on which price will be set. A clear understanding and shared expectation among growers and grain buyers about how the price of the grain will be set is vital to avoid misunderstanding and damage to the marketing programme. Currently the price of triticale grain in the Southeast is equal to that of maize and feed wheat, and in fact triticale grain is commonly mixed with feed wheat. In general, higher valuation of triticale grain is favoured by its higher lysine and threonine concentrations, but that tends to be offset by slightly lower energy values than maize. Some varieties of triticale may command a premium over the price of maize once they are available in quantities large enough to warrant separate storage and adjusted feed formulation. Recent research documenting the benefits of triticale for phosphorus feed use and effluent management may help strengthen demand and prices.

The efforts at the two ends of the marketing chain create and establish the total value of the product and the context within which all the other necessary links in the marketing chain must be filled. The outcome of the ongoing marketing efforts will reveal whether that total value is enough to sustain the efforts of the breeding programme and all those whose fulfil the other necessary links in the two marketing programmes in the Southeast.

A CASE STUDY: TRITICALE MARKETING STRATEGIES IN MEXICO

Potential of triticale to meet important needs

Mexico has long been an important centre of triticale breeding and research, but almost thirty years after the release of its first triticale varieties the area planted to triticale there remains small. Farmers who are familiar with the crop consider it to be a productive alternative, but uncertainties about markets for the crop limit its adoption. A vicious cycle persists of farmers not growing the crop because of uncertainties about markets and end-users not using it because of insufficient availability and lack of knowledge about the functionality of new varieties.

Despite the slow rate of adoption and obstacles to more widespread production, the potential for triticale in Mexico remains compelling. The foundation of this potential is the superior productivity of triticale compared to wheat, its superior tolerance to drought, diseases and low and high pH, and its suitability for some of the same uses for which wheat is currently used in Mexico. As a result of the North American Free Trade Agreement (NAFTA) among Canada, Mexico and the United States of America, wheat from Canada has displaced domestically produced wheat for food products in Mexico. Wheat produced in Mexico is now used primarily for animal feed. Triticale grain could be used for these same feed uses and in fact could be worth more than wheat for those uses depending on the amino acid and energy content of the specific varieties involved. Higher yields and comparable or superior feed value make triticale a superior alternative to wheat production for Mexican farmers, especially in the high-plateau and low-rainfall areas where the performance of triticale has been particularly good compared to wheat. In addition to the potential of triticale grain as a feed grain, Mexican livestock and forage producers have found that triticale forage is superior to oat forage for meeting the need for

TABLE 6
Representative yields and crop values for triticale in Mexico, 2002

Triticale crop	Range of yields (*kg/ha*)	Range of crop values per kg (*pesos/kg*)	Range of crop values per ha (*pesos/ha*)
Flower-stage forage	3 400-5 000	1.00-1.25	3 400-6 250
Grain-stage forage	4 000-7 000	1.00-1.25	4 000-8 750
Rainfed grain	2 000-7 000	1.50	3 000-10 500
Irrigated grain	>8 000	1.50	>12 000

forage for milk and meat production. In addition to its use for feed, triticale can meet an important need in Mexico for food use. Mexico does not produce enough maize to meet demand for food. A blend of 10 percent triticale and 90 percent maize would address that deficit without detracting from product quality. Triticale grain is reported to have a sweeter taste than wheat and is considered superior to wheat for blending with maize. The potential of triticale to meet these fundamental needs in Mexico motivates ongoing efforts to develop markets for the crop there.

Current use of triticale

Although grain for feed and eventually for food is the ultimate objective of efforts to expand production of the crop in Mexico, most of the triticale currently grown in Mexico is used as forage for cattle. The harvested triticale forage is fed to cattle as green forage at harvest time, or made into silage or hay for feeding during the dry season when forage is in short supply. Most of the triticale forage used for milk production is harvested at the flowering stage of development, while some is harvested later at the dough stage when the kernels are between a milky and hard-grain consistency. Protein is higher at the flowering stage, while the later harvest stage is rich in energy and has higher yield. Farmers report that triticale produces higher forage yield than oats and that beef cattle and dairy cows produce more meat and milk with triticale forage than with oat forage; and the meat produced is better. Forage yield is between 3 400 and 5 000 kg/ha at flower stage and between 4 000 and 7 000 kg/ha at hard-grain stage (Table 6). The triticale forage is valued from 1 to 1.25 pesos/kg (10 pesos/US$1).

One limitation to the production and use of triticale forage in the dough and hard-grain stages when yield is highest is the presence of awns on the plants of the main varieties of triticale now grown in Mexico. Awns, or ‘beards’, are needle-like projections on the grain heads that can injure livestock and make the forage less palatable. ‘Beardless’ or reduced-awn varieties that are becoming increasingly popular in the south-central United States of America bordering Mexico are not currently available in Mexico. Seed production of these varieties in Mexico is difficult because they are late-maturing, winter types, and seed cannot be imported because Mexico prohibits the importation of triticale seed from the United States of America.

Efforts to expand production and use of triticale grain

Expansion of the production and use of triticale in Mexico is hindered by several obstacles that limit the adoption of crop technology in general and by some obstacles that are specific to new crops such as triticale. The more general obstacles include lack of awareness about new technology, lack of financial resources to purchase the technology and limited access to inputs and information to complement the new technology.

Improved crop varieties are an important form of potentially beneficial new technology. Lack of financial resources is a major obstacle for many Mexican farmers for purchasing seed of the improved varieties. The significance of that financial constraint, and the linkage between improved varieties and inputs, is highlighted by the patterns of use of certified seed in Mexico over the past thirty years. During the period from 1970 to 1990, 90 percent of the wheat seed planted by Mexican wheat farmers was certified. During that period, average wheat yield increased every year because of the use of certified seed, fertilizer, irrigation and mechanization. In 1990, Banrural, which gave credit to the *ejidos* farms for purchase of certified seed and fertilizer, was closed, and the use of certified wheat seed dropped to less than 50 percent. Consequently, the rate of increase in yields declined. Amazingly, in 1996 in the state of Mexico, which for over 50 years has been the location of many important research centres (International Wheat and Maize Improvement Center [CIMMYT], Instituto Nacional de Investiaciones Forestales, Agrícolas y Pecuarias [INIFAP], Colegio de Postgraduados in Chapingo, Instituto de Investigación y Capacitación Agropecuaria, Acuícola y Forestal del Estado de

México [ICAMEX] and others), less than 2 percent of the area planted to maize was planted with certified seed of improved hybrids. A survey of farmers by the state of Mexico revealed that they recognized the benefits of certified seed, but indicated that they would not buy certified seed because it was too expensive.

In 1997, the federal and state governments in Mexico began funding in matching amounts a programme called Alianza para el Campo to support Mexican farmers, which addresses the lack of financial resources and other general obstacles to the adoption of improved crop technology. The Kilo por kilo programme, which is part of Alianza para el Campo, offers farmers certified seed of improved varieties at a price equal to the price of grain. The name, Kilo por kilo, conveys the notion that a farmer can purchase a kilogram of certified seed for the same price as a kilogram of the grain that the farmer might otherwise withhold from sale as a commodity and retain for planting. The intent of the programme is to encourage and enable farmers to use certified seed of improved varieties that will increase the yield and profitability of their crops. The programme is limited to purchases of seed for a maximum of 5 ha per farmer. To implement the programme, the government buys seed at the price at which it is being sold in the market, then sells it to farmers at the much lower price of grain. Typically, the market price of certified seed is four times the price of grain, and in the case of improved certified seed of maize, the price is 10 to 25 times that of grain. For example, during 1997, the first year of the programme, certified seed of maize, beans, wheat, oats and barley were all sold to farmers at 1.50 pesos/kg regardless of species or variety. At that time, the market price of maize seed was 15 pesos/kg for open-pollinated varieties and 25 to 35 pesos/kg for hybrids.

The difference between the market price of the seed and the grain price at which the government sells the seed to farmers represents a subsidy to the use of the certified seed. In 1998, the programme was modified to limit the subsidized price to a maximum of 25 pesos so that if a farmer chose to purchase a maize hybrid developed by a private company that has a market price of 35 pesos, the farmer would pay 11.50 pesos/kg, based on the 1.50 pesos for the Kilo por kilo price of grain plus the 10 pesos that the market price exceeds the maximum subsidized price. Triticale has been included in the Kilo por kilo programme since 1999. Notably, triticale was added by the federal government at the strong urging of the farmers' union of small-grain cereals, which is a promising indication of the level of interest in the crop among growers. The Kilo por kilo programme is particularly important for triticale because it facilitates the introduction and adoption of the crop itself and does not simply provide improved certified seed of an established crop. The prices of seed and grain for triticale are similar to those for wheat, 6 pesos/kg for seed and 1.50 pesos/kg for grain. Although federal support for the Kilo por kilo programme was discontinued in 2002, state governments such as the state of Mexico have continued the programme and have involved private seed dealers in the storage, sale and distribution of the seed using state storage facilities.

Beginning in 1997, its first year, the impact of the Kilo por kilo programme has been evident. For example, from 1996 to 1997 the area planted to certified seed of improved maize hybrids increased from 2 to 10 percent. That increase has been maintained, and average yield has increased from 3.0 to 3.8 tonnes/ha as a result of improved certified seed and crop management. Although the Kilo por kilo programme tends to be used most by progressive farmers who are not the group most in need of economic and social assistance, the programme is a good way to communicate and emphasize to farmers the importance of certified seed.

In addition to the government efforts addressing the general obstacles to new crop technology, other government efforts in Mexico have been directed specifically toward expanding the use of triticale. These efforts are most notable and best exemplified by those in the state of Mexico, where the state government's institute for research training and technology transfer (ICAMEX) has promoted both the production and use of triticale grain. In 1996, ICAMEX began an aggressive programme of diffusion (promotion), technology transfer and seed production to encourage production of triticale grain for feed and food use. Diffusion of information about triticale to raise awareness about the crop was accomplished through diverse media, including newspapers, bulletins, ballots (brochures), radio and field days. Triticale production technology was transferred to farmers through numerous 0.4 ha plots of triticale placed with several farmers in each of the potential production areas. Production of triticale seed was accomplished by helping organized groups of farmers produce and market the seed, including helping them to transport seed to grain farmers in areas that are unsuitable for seed production. In promoting triticale and assisting production, ICAMEX focuses on the farmers who are most capable of success and are located in production regions where triticale is well adapted and one of the best crop choices. The ICAMEX encourages those farmers in the targetted regions to produce triticale by supplying them with inexpensive, good-quality seed to get them started.

As a result of the promotion, technology transfer and seed production efforts of ICAMEX over the past five years, and the availability of more and better varieties, the production area of triticale in the state of Mexico is now two to four times larger than it was in 1996 and most likely is larger than the area of triticale production throughout the rest of the country. Based on the acceptance of triticale among farmers who have become familiar with the crop, in each of the last three years ICAMEX has produced and marketed an average of 300 tonnes/year of high-quality seed produced directly by ICAMEX or by farmers who have been assisted by ICAMEX. This available, improved seed is almost half of the seed used by farmers for current triticale production. Although official data on production area are not available, annual planting of triticale in the state of Mexico may now exceed 4 000 ha. To help meet the need for planting seed for that area, in the summer production cycle in 2002, ICAMEX sold 182 tonnes of certified seed of the variety Siglo-21 through the Kilo por kilo programme, enough to plant almost 1 500 ha. Despite recent increases, the area of triticale production in the state of Mexico is less than 10 percent of the potential area for triticale production in the state.

Production of triticale grain in the state of Mexico and the rest of the country is limited by the lack of well-established markets for the grain. In addition to encouraging production of triticale grain, ICAMEX has sought to increase demand for it for both feed and food use. Development of feed markets has been caught in a vicious cycle of limited production because of uncertainties about markets for the grain and limited use because of uncertainties about supply. Farmers are understandably reluctant to produce triticale grain without assurances about markets for it, while livestock producers will not alter their feeding rations if they are not certain they can obtain an adequate supply or that triticale grain will have any advantages for them as a feed. The livestock producers indicate that 1 000 tonnes of grain are needed for meaningful evaluation of triticale grain as a feed at a commercial level. No individual farmer is likely to be willing to produce such a quantity under these circumstances, so ICAMEX is working to organize groups of farmers who together can produce the needed quantities.

For food use, one goal has been to make the food industry aware of the availability of improved, new varieties of triticale that are good for flour production and for blending with wheat to make cookies and bread. ICAMEX is trying to convince the major food company, Bimbo, to use triticale in the production of cookies, doughnuts and tortillas. It also is working with the Integral Development of the Family (DIF) government organization to convince them to use triticale for cookies and tortillas provided to children for breakfast in public schools. ICAMEX is seeking other large companies as customers for triticale grain. As soon as more is learned about whether triticale flour can be blended with maize flour to produce better tasting tortillas, ICAMEX will encourage the use of triticale by Maseca and Minsa, the companies that process maize for almost all the *tortillerias* (tortilla-making establishments) in the country. Those two companies process more than 5 million tonnes of maize annually, so that a blend with 10 percent triticale and 90 percent maize would represent demand for more than 500 000 tonnes of triticale. Satisfying demand of that amount would require all the grain produced in the high-plateau regions of Mexico. The grain yield of triticale in rainfed conditions is between 2 and 7 tonnes/ha, while under irrigation it is more than 8 tonnes/ha.

In conjunction with the market development efforts by ICAMEX, some farmers are seeking to increase the selling price of the triticale grain that they produce by storing it so they can deliver it to grain users throughout the year. One possibility for storage facilities is the use of infrastructure that once belonged to the Compañia Nacional de Subsistencias Populares (CONASUPO), the organization of the federal government that was formerly in charge of aggregating, storing and setting the price of maize, beans, rice and wheat produced by Mexican farmers. Although current markets for triticale grain in Mexico are still small and uncertain, if ICAMEX continues to organize and assist triticale producers and to develop markets for the grain, it is likely that markets for triticale grain in Mexico will be established for both feed and food use within three years.

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Country reports

Triticale in Algeria

A. Benbelkacem

Algeria is a country that is extremely deficient in food grains as well as in feed grains. A good proportion of the cereal land is highly eroded and thus low in fertility. In addition, annual rainfall on which the cereals depend is very erratic. During the last two decades, 1.8 million tonnes of cereals per year have been produced on average in Algeria. This level of production covers only one-third of the consumption needs (human and livestock) (Benbelkacem, 1998).

Triticale (X *Triticosecale* Wittmack) was grown in Algeria on a total area of about 20 500 ha in 2001 (Table 1). More than 60 percent of the area was grown in the northeast region of the country. Triticale is grown with the aim of reducing maize and barley imports. The crop is mainly grown for forage production as a grain feed or for dual purpose (forage and grain).

The area cropped to triticale reached a maximum of 35 000 ha in 1996/97 (Table 1). This area has been stable at around 21 000 ha during the last decade. Grain yield average is 1.5 tonnes/ha, which is relatively higher than other cereals with an average of 1.2 tonnes/ha (Statistiques Agricoles, 2000).

TABLE 1
Area, production and grain yield of triticale in Algeria, 1991-2001

Year	Area (*ha*)	Production (*tonnes*)	Grain yield (*tonnes/ha*)
1991/92	15 000	27 000	1.8
1992/93	17 000	27 200	1.6
1993/94	19 750	27 650	1.4
1994/95	21 500	25 800	1.2
1995/96	23 000	48 300	2.1
1996/97	35 000	66 500	1.9
1997/98	21 500	27 950	1.3
1998/99	22 500	24 750	1.1
1999/00	18 000	27 000	1.5
2000/01	20 500	28 700	1.4
Average	21 375	33 085	1.5

TRITICALE PRODUCTION

In general, the cultivation of triticale does not differ from that of other cereals. There are three main different agro-ecological regions where cereals are grown in Algeria.

Littoral and sub-coastal area

This region is characterized by deep, good soils and a Mediterranean climate with cool, wet winters (rainfall more than 550 mm/year). Rainfed cereals are the dominant crops. Livestock production is often integrated in the farming systems of the region. The main biotic stresses are fungal and viral cereal diseases, mainly rusts, powdery mildew, the different Helminthosporium species of wheat and barley, and barley yellow dwarf virus (Sayoud, 1994).

Interior and high plains

Rainfall in these areas is irregular over the year and ranges from 350 to 500 mm in uneven distribution. The winters are mild to cold with high frequencies of frost during the year. Soils are deep to shallow moving from north to south. Most of the cereals are grown intensively. The major abiotic stresses are early drought, cold winters and late heat during the grainfilling period. The biotic stresses include few diseases with less severity in the higher regions.

High plateau

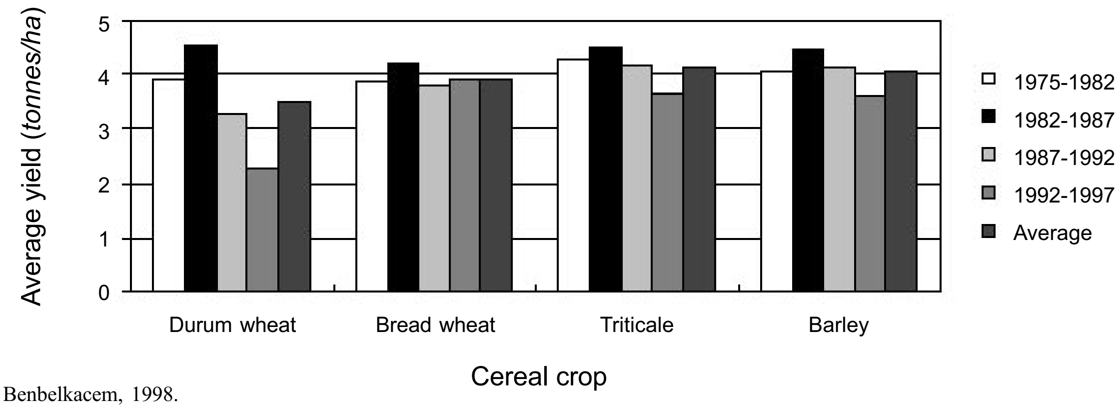
The average altitude in this region is over 1 000 m. The climate is continental with cold winters and hot summers. Soils are shallow. This area is referred to as a semi-arid region. Cereals are grown extensively. Barley is the main crop integrated with livestock production, mainly sheep and goats. The main abiotic stresses are cold and frost during the flowering period. Some diseases in wet years and Russian wheat aphid and root rot can cause some problems (Sayoud, 1994).

Most of the triticale is grown in the interior plains and in the sub-littoral area (favourable area). However, in the high plateau triticale production is better than the other cereal species.

USES OF TRITICALE

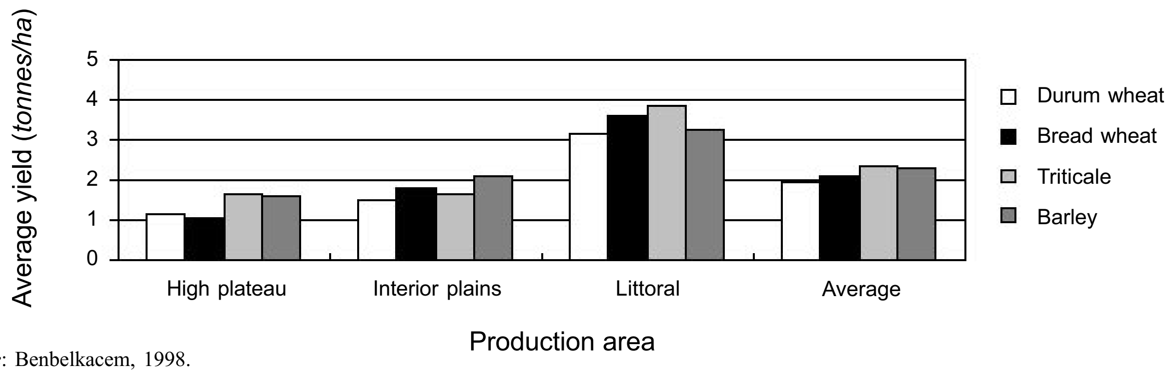
The utilization of triticale in Algeria is roughly as follows: human consumption 5 percent, forage crop (hay or silage)

FIGURE 1
Average yield per period of time for different cereal crops grown in Algeria, 1975-1997



Source: Benbelkacem, 1998.

FIGURE 2
Average yield per cereal crop for different cereal-producing areas in Algeria, 1992-1995



Source: Benbelkacem, 1998.

60 percent, feed grain 30 percent and the remaining 5 percent is kept for seed increase (unpublished data). As forage, triticale is favoured for its ability to be grazed early in the winter when no other green fodder is available (Plate 1) and to be cut later in the season as a silage, hay or grain crop (Plate 2). Late harvest is not suitable because the high percentage of dry matter can be problematic for forage conservation in silos. The grain is mostly used as a substitute for maize in animal feed. The shortage of silage has been a primary constraint on the development of dairy cattle during the winter season and early spring (Benbelkacem, 2002).

TRITICALE IMPROVEMENT

The data collected from different sites (Figure 1) show that on average triticale, globally over years, outyielded barley, bread wheat and durum wheat by 2, 6 and 16 percent, respectively. This trend is also valid when the data from the same table are compiled per period of time. Except in two cases, triticale performed better than wheat or barley (Benbelkacem, 1998).

Grouping the data according to the agro-ecological area shows the net advantage of triticale cultivars over other cereal crops in yield performance (Figure 2). As expected, in the high-plateau area triticale yielded up to 137 percent of bread wheat, 130 percent of durum wheat and 104 percent of barley. In the intermediate zones (plains), triticale was less yielding than bread wheat or barley but gave 8 percent more than durum wheat. In the most favourable zones, triticale also outyielded bread wheat, barley and durum wheat by 6, 16 and 19 percent, respectively. The winter-type triticales introduced in Algeria in 1992 were not adapted and thus performed poorly (Pfeiffer and Fox, 1991).

TABLE 2
Yield performance in early introduced and released triticales

Cultivars	Grain yield (*tonnes/ha*)	Percentage to check (*%*)
Cinnamon	2.65	100
M2A	2.59	98
Bacum	2.78	105
Beagle	3.05	115
Average	2.77	-

Source: Benbelkacem, 1988.

TABLE 3
Yield performance of triticale cultivars over different locations, 1982-1997

Cultivars	Grain yield (*tonnes/ha*)	Percentage to check (*%*)
Chenoua=Beagle	3.21	100
Cherea=DOC7	3.96	123
Chelia=Eronga	3.88	120
Meliani=Clercal	3.05	95
Trick	3.13	97
Rhino 4.1	4.24	132
REH/HARE	3.86	120
MER/JLO	3.87	120
Lamb 2	4.08	127
Fahad 5	4.04	125
IFTT314=IFRI	2.86	89
BGL/CIN//MUSX/4/DE LF99/3/M2A/SNP/BGL	3.73	116
Average	3.66	-

As in every other programme in the world that started with the incomplete Armadillo-derived type cultivars, yield gains were slow in the beginning. In that period, in the late 1970s, Cinnamon (check) performed on average 2 percent better than Maya 2 Armadillo but 5 to 15 percent less than Bacum or Beagle (Table 2) (Benbelkacem, 1988).

In the following 15 years (1982-1997), it appears that the introduction of the complete-type triticales improved the yield potential. Compared to Beagle (check), cultivars such as Rhino 4.1, Lamb 2 or Fahad 5 showed a yield gain of 132, 127 and 125 percent, respectively (Table 3).

Nowadays, the varieties most used by farmers are: Chelia, Cherea, Lamb 2, Meliani and IFRI. All these varieties are in a slow seed increase process. Seed availability is a problem because most of the triticale fields are grazed, cut as forage or silage or harvested and used as whole grain for feed (Benbelkacem and Zeghida, 1996).

Fresh fodder

Triticale is higher than oats, barley or durum wheat for total biomass, forage dry matter and height by 104 to 144 percent, 105 to 170 percent and 104 to 144 percent, respectively (Table 4) (Benbelkacem, 2002).

Grain quality

Compared to wheat, triticale shows better protein and lysine contents (Table 5) with 2.8 and 0.19 percent more, respectively.

Fodder nutritional quality

For silage and fresh feed crops, it is important that the plants contain varied nutritional components. In order to identify the feeding value, the nutritional components of triticale, barley and wheat were determined before silage was harvested. The results (Benbelkacem, 2002) proved that triticale had a higher and fresher feed resource and forage quality than barley or wheat in all traits (protein,

TABLE 4
Plant height, grain yield, total biomass, straw to grain ratio and forage dry matter of triticale compared to other cultivated cereals at Elkhroub Station, Constantina, Algeria, 1998-2001

Crop	Plant height (*cm*)	Grain yield (*tonnes/ha*)	Total biomass (*tonnes/ha*)	Straw to grain ratio	Forage dry matter (*tonnes/ha*)
Durum wheat	90	3.08	6.8	2.20	5.1
Bread wheat	85	4.12	7.9	1.92	5.9
Barley	105	3.67	8.6	2.34	6.8
Triticale	130	3.96	9.8	2.47	8.7
Oats	125	3.80	9.5	2.50	8.3
Mean	107	3.72	8.5	2.28	7.0

Source: Benbelkacem, 2002.

TABLE 5
Protein and lysine content in triticale and wheat, 1998-2001

Crop	Protein range (%)	Average (%)	Lysine range (%)	Average (%)
Triticale	10.25-21.50	15.2	0.29-0.67	0.51
Wheat	7.90-19.82	12.4	0.23-0.42	0.32

TABLE 6
Forage quality of triticale compared to barley and wheat, 1999-2001

Crop	Water (%)	Protein (%)	Fat (%)	Cellulose (%)	Sugar (%)	Ash (%)	Carotene (*mg/g*)
Triticale	71.22	4.44	1.12	10.24	2.31	4.01	1.21
Barley	76.33	3.55	0.91	8.74	3.12	2.63	0.82
Wheat	68.41	3.01	0.78	7.98	2.41	2.32	0.97

Source: Benbelkacem, 2002.

TABLE 7
Milk quality and milk yield of oat, barley and triticale silage from a sample of dairy cattle farmers in northeastern Algeria, 2001/02

Silage	Protein (%)	Fat (%)	Lactose (%)	Water (%)	Daily milk (*yield/day/cow*)
Oat	3.04	3.17	4.68	88.77	37
Barley	3.12	3.31	4.59	89.02	35
Triticale	3.21	3.43	4.71	86.65	40

Source: Benbelkacem, 2002.

fat, cellulose, ash and carotene) except for water content and sugars (Table 6).

Application of triticale as feed

Triticale silage is very popular for feed nowadays at the farmer level. It is performing better than barley or oats in quantity and quality. Feeding trials from different northeastern counties of Algeria indicated that the quantity of milk produced by feeding triticale silage was 12.5 and 7.5 percent more over barley and oats, respectively. In addition, the quality of milk from cows fed with triticale is better (Table 7).

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PLATE 1
Animals grazing on triticale in Algeria
A. Benbelkacem

PLATE 2
Use of triticale for silage
A. Benbelkacem

Triticale in Australia

K.V. Cooper, R.S. Jessop, N.L. Darvey

Triticale is a mainstream crop in Australia, mostly as spring types grown for grain production and also as longer-season, dual-purpose types grown for fodder use as hay, silage or grazing followed by grain production. The grain is primarily used as stock feed, with a low level of triticale use in food products. Most of the grain is used domestically although small amounts are exported. Triticale improvement programmes continue to release a steady stream of cultivars. Improvement in grain yield coupled with rust resistance remains the general aim of breeders, with resistance to cereal cyst nematode, improved quality and agronomic characteristics also being selected for in breeding. Both locally generated germplasm and material from the International Maize and Wheat Improvement Center (CIMMYT) are used for breeding and selection purposes. Current spring-grain cultivars (2002) are: Abacus, Credit, Everest, Muir, Prime322, Tahara, Tickit and Treat. Dual-purpose cultivars are: Madonna, Maiden, Hillary, Jackie and Eleanor.

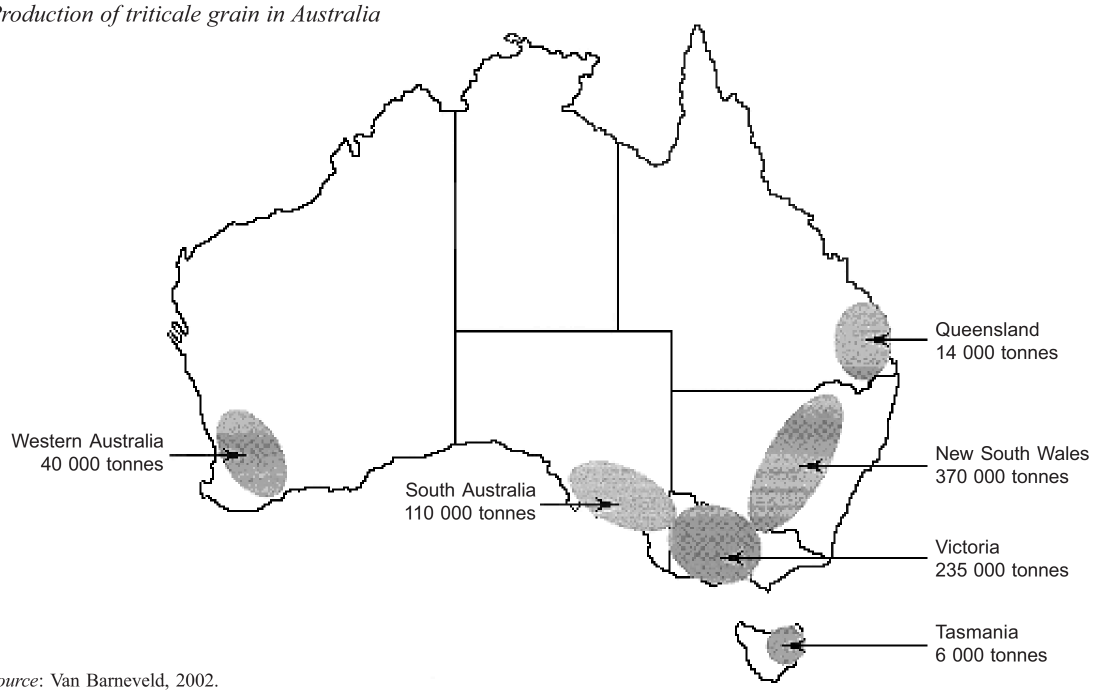
HISTORICAL BACKGROUND

Triticale was introduced into Australia in the early 1970s as experimental lines for evaluation. Breeding and selection programmes were initiated at several universities and state government departments of agriculture, and a number of varieties were released, which were mostly spring-grain lines introduced from CIMMYT. Triticale was quickly taken up as a useful crop for grain and fodder production on acid and waterlogged soils and for producing an economic and soil-conserving crop on lower rainfall, nutrient-impoverished soils. Initially, triticale was mostly used on-farm or traded locally as stock feed. It was often sought as a more easily-traded feed grain than wheat, which had to be marketed through the Australian Wheat Board. On the other hand, as triticale was not a well-known grain, and as the quantity available was limited, in some areas triticale could prove difficult to sell for a good price, which tended to limit its adoption. The first Australian cultivar was Growquick, a later-maturing line of poor-grain type most suitable for grazing use. By the mid-1980s, 11 grain cultivars had been released: Satu and Dua from the University of New England, Armidale, New South Wales; Samson, Ninghadhu and Bejon from the University of Sydney, New South Wales; Coorong, Venus and Currency from the University of Adelaide, South Australia; and Towan, Tyalla and Toort from the Victorian Department of Agriculture, Victoria. In the early 1980s, wheat stem rust races evolved in Queensland (McIntosh and Singh, 1986), which were virulent on these cultivars with the exception of Ninghadhu and Bejon. In order to reduce the likelihood of rust epidemics and further evolution of virulent races, the rust-susceptible cultivars were no longer recommended, and breeders sought to produce cultivars with full rust resistance. Ninghadhu and Bejon have now been replaced by improved cultivars. In the late 1980s, two more CIMMYT lines were released, Muir by the Western Australia Department of Agriculture and Tahara (Brouwer, 1989) by the Victorian Department of Agriculture. Tahara in particular has been a very successful cultivar, forming the mainstay of the Australian triticale industry for more than ten years. The reliability of Tahara's grain yield in all grain-growing areas, coupled with resistance to nematodes, supported a gradual increase in cropping area and production. The increasing amount of triticale produced and many years experience of good results within the stock feed industry gave users confidence in this grain, driving an increasing demand for triticale and improved prices. As more buyers in more locations have sought to buy triticale, more growers have adopted triticale in their farm operations.

CURRENT PRODUCTION

It is not possible to obtain an exact figure for current area and production, as much triticale is used on-farm rather than sold, but figures from the Australian Bureau of Statistics, Australian Bureau of Resource Economics, local district agronomists and grain-buying organizations would indicate that the production of triticale grain in 2001 was at least 800 000 tonnes. Thus triticale is a significant but minor crop compared with wheat (21 168 000 tonnes), barley (5 596 000 tonnes) and canola (1 661 000 tonnes) (O'Connel, 2002). Triticale is grown across the grain belt of Australia, with maximum grain production in New South Wales (370 000 tonnes),

FIGURE 1
Production of triticale grain in Australia



Source: Van Barneveld, 2002.

followed by the states of Victoria (235 000 tonnes), South Australia (110 000 tonnes), Western Australia (40 000 tonnes) and smaller amounts in Tasmania (6 000 tonnes) and Queensland (14 000 tonnes) (Figure 1). Within these regions, some triticale is grown for grazing, hay and silage production. The average grain yield of triticale is about 2.5 tonnes/ha, although these yields vary locally from less than 1 tonne/ha in lower rainfall areas and areas with soil problems to more than 7 tonnes/ha in higher rainfall areas with more fertile soils. Triticale is grown in areas with an annual average rainfall of about 300 mm through to at least 900 mm. Very little triticale is irrigated. Triticale for grain is generally sown in autumn (May-June) and harvested in summer (December-January). Triticale for grazing or as a green manure may be sown at other times if sufficient water is available. Triticale is commonly sown between rows of vines in vineyards where the benefits of triticale in reducing weeds and increasing organic matter in the soil are valued.

Farmers appreciate the ability of triticale to tolerate periods of drought through the growing season, and at the other extreme, its tolerance of waterlogging. Triticale grows productively on acid soils where the high availability of aluminium ions reduces the economic yield of many other crops and on alkaline soils where certain trace elements, e.g. zinc, manganese and copper, are deficient for most wheat, barley and oat cultivars. Large areas of soils with high levels of boron, which reduces yields of other cereals, are more successfully cropped with triticale. Traditionally grown in poorer conditions, triticale was treated as a ‘forgiving’ crop needing less care and attention. However, increasing experience of triticale’s good response to fertilizer application and increasing demand for its use as animal feed have led to more triticale being grown on better soils with better management.

Many growers use triticale as a disease break in their rotations and value the benefits of triticale for its contribution to soil conservation. Thus triticale assists in maintaining soil health by the reduction of nematodes, such as *Pratylenchus neglectus* and *thornei* (root lesion nematodes) and *Heterodera avenae* (cereal cyst nematode), and a range of fungi and bacteria that build up in the soil, reducing yields when the same crop species is grown repeatedly. Other favoured characteristics of triticale are its resistances to barley yellow dwarf virus, mildew and rusts, which may cause significant yield reductions in wheat, barley and oats. The extensive root system of triticale binds sandy soils, and the fibrous stubble reduces wind and water erosion.

TRITICALE BREEDING

Breeding programmes

Triticale breeding continues to be undertaken at the University of Adelaide, University of New England and University of Sydney. Various funding sources have contributed over the years, although this has tended to be sporadic and at a lower level than that supplied for research on other crops. The Grains Research and Development Corporation (GRDC), which collects levies from crops including triticale, took on the support of triticale breeding in 1991 and continues to fund small programmes working on the improvement of spring-grain varieties at the University of Adelaide and longer-season, dual-purpose varieties at the University of Sydney. Bunge Meat Industries (Corowa, New South Wales), the largest pork producer in Australia, is supporting a programme at the University of New England. Major selection criteria are high grain yield or forage production capacity and resistance to triticale stem rust. Significant progress in grain yield, adaptability, disease resistance, grain quality and fodder production continues to be made.

Breeding spring-grain types

At the University of Adelaide, breeding material is mostly derived from crosses involving locally produced primary triticales and introduced germplasm. The cultivars Abacus, Credit, Treat and Tickit derive from a collection of octoploid and hexaploid primary triticales produced at Waite Campus 1982-1985 (Cooper and Driscoll, 1986). Further primary triticales based on locally adapted durums (*Triticum turgidum* L.) obtained from the University of Adelaide Wheat Breeding Program crossed with the Adelaide University released Bevy rye (Cooper, 1998a) are now entering the crossing programme. Primaries are top-crossed before entering the selection programme. A modified F_2 progeny method is used with reselection as necessary from F_7 onwards. Selections from F_2 plots and reselections from later generations are grown as head hills in an irrigated summer nursery. Replicated yield trials are conducted from F_5 onwards. Introduced germplasm, mostly from CIMMYT, is multiplied and assessed for suitability as parental material or direct variety releases. A total of 12 000 breeders' trial plots (plots approximately 4 m^2 in area) are sown across four major sites in South Australia and one in the southern coastal region of Western Australia. Locations have a range of soil types including deep sand, waterlogged acid and alkaline, and annual average rainfall varies from 350 to 850 mm. Selected advanced lines and check cultivars are trialled (larger plots, e.g. 15 m^2) by cooperators from state agricultural organizations in South Australia (eight sites), Victoria (five sites), New South Wales (seven sites) and Western Australia (one site). It is now common for breeders' lines to outyield Tahara, the main check variety, particularly at the higher rainfall sites. A typical year's data summary table is presented as Table 1.

Callington, Cleve and Birdwood are South Australia Breeder's sites. Greenpatch, Minnipa, Wharminda, Piednippie, Frances, Pinnaroo and Turretfield are South Australian Field Crop Evaluation Program sites. Coomalbidgup is the Western Australia breeding trial site. Rutherglen, Walpeup and Streatham are Agriculture Victoria sites. Manildra, Gerogery, Lowesdale, Temora and Mayrung are New South Wales Agriculture sites.

Although triticale stem rust has not been recorded recently in Australian triticale crops (as susceptible varieties have not been grown for some years), resistance to this disease is considered an essential requirement for a variety release. From generation F_4 onwards, all material is tested by the National Rust Control Program (NRCP) of Sydney University, Cobbitty, for resistance to triticale stem rust, and susceptible lines are discarded or re-enter the crossing programme. Generally, a high proportion of locally produced crosses are resistant, whereas the majority of CIMMYT lines are susceptible. Credit (Cooper, 1998b) was released as a rust-resistant replacement for the susceptible variety Currency. Lines put forward for replicated yield trials are tested for resistance to *Heterodera avenae* (cereal cyst nematode, CCN) by the SARDI Field Crop Pathology Laboratory. Tickit (Cooper, 2000) is CCN-resistant.

Another breeding aim is improved test weight, sought particularly because the current delivery standard for test weight for triticale, 65 kg/hl, may not be obtained by some varieties in some environments. Treat (Cooper, 1998b) has regularly produced grain up to 6 kg/hl above Tahara.

Varieties with different adaptive and plant type characteristics are sought to suit the wide range of conditions across the Australian grain belt. Breeders' trial sites tend to direct selection to a fairly narrow range of medium-season maturity, but earlier- or later-season varieties are specifically sought. Abacus (Cooper, 1992, 1994) matures a few weeks later than most grain varieties and is still proving popular. Treat matures a few days ahead of Tahara. Some longer-season (up to three weeks later maturing) and shorter-season (one week earlier maturing) candidates are being considered for release as cultivars. Whilst the tall straw of triticale is a desired characteristic in low-rainfall areas where it provides an

TABLE 1
Performance of triticale varieties at selected trial sites in Australia, 2001/02

Site	Tahara yield[a] (*tonnes/ha*)	Treat (*% Tahara*)	Credit (*% Tahara*)	Tickit (*% Tahara*)	Everest (*% Tahara*)	Muir (*% Tahara*)
Callington	2.67	103	106	104	111	106
Cleve	2.81	100	101	95	103	101
Birdwood	5.02	100	104	103	107	98
Greenpatch	4.33	96	101	95	91	96
Minnipa	2.65	95	97	95	100	96
Wharminda	1.47	107	84	105	86	100
Piednippie	2.06	86	87	104	90	95
Frances	3.41	113	119	112	109	112
Pinnaroo	3.03	84	97	94	91	85
Turretfield	4.74	110	108	110	112	110
Coomalbidgup	4.30	105	103	96	98	96
Rutherglen	6.34	104	107	109	109	108
Walpeup	3.62	98	98	93	100	-
Streatham	4.56	130	124	112	118	-
Temora	2.91	103	111	107	110	92
Manildra	5.14	102	102	104	104	97
Gerogery	7.40	102	102	102	98	105
Lowesdale	3.64	100	111	114	97	95
Mayrung	7.17	94	101	103	93	99

[a]Grain yield = mean of three or four replicates, analysed by ASREML spatial analysis.

improved height for harvesting, the excessive height of triticale in high-rainfall, high-yielding environments can be a problem. Generally, selection is aimed towards height reduction. Abacus, Credit and Tickit are about 5 cm shorter than Tahara in 600 mm annual rainfall. Considerably shorter lines and those with stronger straw strength with reduced lodging in high-yielding environments are also sought. Material with reduced awns is being tested for suitability for hay production.

The University of New England programme has concentrated on using germplasm from CIMMYT, both for direct release as cultivars and for crossing purposes. Everest, a tall variety with grain of high test weight was released in 1999, and further CIMMYT selections are currently undergoing preparation for release. Prime322, which is derived from a cross between two CIMMYT lines, was released by the University of Sydney in 2001.

Breeding dual-purpose triticales

Since the early days of European settlement in Australia, oats has traditionally been the main grazing cereal crop. However, dual-purpose triticale cultivars, which have at least the equivalent dry-matter production capacity of oats combined with better tolerance of waterlogging and acid soils and better resistance to foliar diseases, are increasingly being sown instead of dual-purpose or grazing oats. Dual-purpose triticale retains its grain better than oats, and current prices for triticale exceed those of oats, encouraging its replacement with triticale.

The development of dual-purpose cultivars has been undertaken by the University of Sydney and University of New England. The aim has been to release longer-season lines with some winter habit (but not full-winter types such as those grown in Europe) that can be sown in eastern Australia in February/March (late summer/early autumn). These varieties make sufficient growth in autumn to allow winter grazing, and the stock are removed to allow the crop to recover to produce grain for a summer harvest. Releases in the 1980s included Madonna, with excellent dry-matter production in the cooler highland regions of New South Wales, and Empat, which had better grain yields but only produced good grazing in late winter. The cultivar Tiga was released in 1987 with high levels of dry-matter yield in autumn to give good early-winter grazing. More recent dual-purpose cultivars are Maiden, released in 1999 (Roake, 1999), and Jackie and Hillary, released in 2000 (Roake, 2001), all of which have high yields of dry matter and good grain recovery after grazing. Eleanor (2001) has also given excellent dry-matter yields in many regions of New South Wales. The grazing/dual-purpose triticales have been mainly used for direct grazing, but increasing interest is being shown in the production of triticale silage and hay. Jackie, which has reduced awns, is resistant to cereal cyst nematode and is earlier maturing than the other dual-purpose cultivars, is gaining popularity for hay production in South Australia.

SEED PRODUCTION AND CULTIVAR AVAILABILITY

There is no standard way of releasing triticale cultivars. The releasing institution decides on a suitable release method for each cultivar individually. In general, a cultivar bred in Australia will be released with Plant Breeders' Rights (PBR) whereby ownership is attributed to a breeder, institution hosting the work, or funding suppliers (or combination of these). A detailed description of the variety, showing its distinctness, uniformity and stability is submitted to the Plant Breeders' Rights Office. Growers must initially buy these PBR cultivars from a specific source and are not permitted to trade the seed among themselves. Some PBR varieties have a royalty payable on the seed, or payable when the crop is delivered for sale, the idea being that this royalty is returned to the owners. Credit, Prime322, Tickit and Treat are PBR protected. Abacus is now a freely traded cultivar, although it was protected by PBR for nine years. Some varieties may be simply released without PBR protection, e.g. Everest, which can be bought and sold without restriction. The releasing institution chooses a seed company who will be granted the licence to handle a particular cultivar. A cultivar generally undergoes several years of seed production to a specified standard (free of weeds and other cereals, good germinability) before farmers gain access to the cultivar. The breeder and the commercializing company usually work together on promotion of the cultivar to growers. Adoption of some cultivars in some areas has been limited by reduced availability of sowing seed.

TRITICALE USE

Triticale represents a true premium livestock grain in Australia, which unlike wheat and barley has little competition from human food markets. About 30 percent of the triticale grain in Australia is retained on-farm with the remainder being traded. The grain may be sold directly to an animal enterprise (e.g. a dairy farm or piggery), a feed-mill that processes raw materials to produce compound feeds, or to a grain-handling organization, which provides bulk storage and markets larger parcels of grain.

The nutritional value of triticale remained underrated for a long time, and triticale was usually sold at a discount to wheat and barley. As information about the nutritional value of triticale increases and users gain more experience with this grain, demand continues to increase with an associated rise in purchase price offered. Production in Australia has now reached a critical mass, with sufficient supplies reliably available for users to be willing to formulate their rations based on triticale. Triticale currently sits between milling wheat and feed barley in price.

Current Australian triticale cultivars are free of appreciable levels of anti-nutritional factors, and triticale is basically used in rations as a substitute for wheat. Growing environments have a greater influence on the nutritional value of grain samples than does the cultivar. As triticale is grown in a wide range of environments, including the poorest of growing conditions, protein content of samples can vary considerably (in a range similar to that of wheat), although energy content is fairly stable across growing environments. Triticale is valued as a palatable, highly digestible grain for feeding pigs, chickens, cattle, sheep, deer and horses and all stock generally (Van Barneveld, 2002).

Very small amounts of triticale are used for human consumption. Thus wholemeal flour and flakes (steamed and rolled grain) are available in some specialist shops. Triticale whole grains are a component of some breads produced on a large scale, and wholemeal flour is used to a small extent in bread making. Although triticale is appreciated by some people for its delicious flavour, high fibre content and ease of use in baking (Cooper, 1985), triticale is not generally well known to Australian consumers, and there has been insufficient demand for its significant use in food products.

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Triticale in Brazil

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Triticale (X *Triticosecale* Wittmack) is an important crop for the winter season in southern Brazil. It was introduced as a cultivated species for experimental purposes in Brazil in the early 1960s (Mundstock, 1983).

Since the beginning of triticale cultivation in the southernmost state of Brazil, Rio Grande do Sul, in 1982, triticale area has increased substantially. From 1987 to 1991 in southern Brazil, the area increased steadily to between 30 000 and 40 000 ha (Baier *et al.*, 1994). The main reason for such an increase in area was that the prices and uses of triticale grain and flour were the same as those for wheat. Also, the Brazilian government guaranteed acquisition of all triticale and paid the same price for triticale and wheat. In 1990, with the interruption of the Brazilian government's support for triticale and with wheat commercialization, the economy of these products changed considerably with negative consequences on their cultivation.

Because of the slightly lower production costs of triticale compared to wheat and due to its use as a component in rations for poultry and swine feed, the area cultivated with triticale has doubled since the beginning of the 1990s. Some incentive for triticale cultivation also resulted from the organization of the Second International Triticale Symposium in October of 1990 in Brazil. In addition, the marketing devoted to triticale and the support given to producers by the swine and poultry industries enhanced triticale programmes, improving, to a certain extend, its value as animal feed (Baier *et al.*, 1994).

Recent data on triticale production in Brazil show significant increases in area, production and yield (Table 1). The major state producers in 2001 were Paraná (86 545 ha), Rio Grande do Sul (21 762 ha), São Paulo (10 000 ha), Santa Catarina (9 831 ha) and Mato Grosso do Sul. The total triticale area in 2001 was approximately 130 000 ha, used mostly for animal feed, as pasture, silage or raw material for feed rations. Moreover, triticale is presently being used for human consumption, including pizza dough and several wheat flour mixtures for cookies and pastas.

Triticale yield has been quite unstable since the beginning of its cultivation in Brazil. In general, the grain yield average has ranged from 1 600 to 2 100 kg/ha in the last decade. In spite of this, the yield potential of triticale cultivars is high. Average yield obtained in research trials was higher than 6 000 kg/ha in several locations. These results are mainly due to the selection of superior genotypes, adapted to the specific environment of production, and the development of better management practices, such as the use of adequate amounts of fertilizers, crop rotation and pest and weed control, which result in better expression of the yield potential of the cultivars.

TABLE 1
Triticale grain production, average yield and area in some states of Brazil

Year	Production (*tonnes*)	Yield (*kg/ha*)	Area (*ha*)
	Rio Grande do Sul		
1992	21 518	2 145	10 034
1996	73 281	1 768	41 459
1999	34 986	1 725	20 284
2000	38 197	1 577	24 226
2001	35 745	1 643	21 762
	Santa Catarina		
1994	15 826	1 860	8 508
1996	32 688	1 543	21 189
1998	9 705	1 550	6 260
1999	11 335	2 054	5 519
2000	-	-	-
2001	9 455	961	9 831
	Paraná		
1992	64 944	1 778	36 532
1996	128 729	2 696	47 742
1999	100 191	2 153	46 528
2000	99 678	1 650	60 403
2001	184 444	2 132	86 545

Source: Embrapa Trigo.

TRITICALE PRODUCTION

In Brazil, triticale is cultivated mainly in the southern states (Figure 1). Most of these areas are cultivated with maize and soybean during the summer season and are not entirely utilized during the winter season, leaving the soil more exposed to erosion in this critical period. Spring growth-habit triticale is the main cultivated type in Brazil.

FIGURE 1
Triticale cultivation in Brazil

It is planted in autumn/winter from April to June. Winter-type triticale genotypes are used only in crosses with spring types to enlarge the genetic variability of spring triticale by introducing new genes and to generate new germplasm with a longer crop cycle that can be used as pasture.

The climate in southern Brazil during the winter is influenced substantially by the polar and tropical air masses. Such phenomena interfere with air temperature, precipitation, sunshine duration and wind thus affecting plant development. The climate of the region is considered subtropical, with rainfall well distributed during the year and varying from 1 500 to 2 000 mm in the states of Santa Catarina and Rio Grande do Sul. In the states of Mato Grosso do Sul, São Paulo and Paraná, annual precipitation ranges from 1 000 to 1 500 mm. In general, the rainy seasons are autumn and winter, affecting the amount of sunshine duration, especially in June and July, due to the increase of nebulosity. During the winter, the entire region can be exposed to frost, especially in higher elevations, and eventually the occurrence of some low-intensity snow showers. The average daily air temperature during the growing period does not limit triticale growth and development except for the possible occurrence of frost during the flowering stage, which may cause high sterility levels in flowers.

When compared to other winter cereals, triticale is less susceptible to low temperatures and water deficit. However, triticale does not resist flooded soils or excess rain during reproductive stages. In addition, one of the greatest climatic limitations to triticale production in Brazil is the occurrence of heavy rains during flowering and maturation, which induces the appearance of foliage and spike diseases, mainly scab. This fungus causes triticale yield reduction, lower grain quality and can limit its utilization for monogastric animals, such as poultry and swine, due to the synthesis of micotoxins in the grain. Since the Rio Grande do Sul and Santa Catarina states have a high frequency of heavy rains during the winter compared to other states, there is a need to develop genotypes that are less susceptible to diseases.

In the eastern coastal areas of the various states, triticale production is limited due to the undesirable condition of the soils and weather for cereal development.

In the southern part of Rio Grande do Sul, the limitation is due to the excess of soil humidity and air moisture. These areas have typical prostrate vegetation, predominantly monocots and some native dicots. The cow and sheep stock of the region have stimulated the search for triticale genotypes that are better adapted to soils with a high risk of flooding and also genotypes with a high potential for use as pasture in the production system of the region.

Favourable inherited traits from parental species, such as high yield and biomass potential, disease resistance, low basal temperature, drought and cold tolerance, deep root system, high-quality grain for certain uses, etc., made triticale a good winter crop for soils with lower fertility levels.

USES

Triticale flour is darker than wheat and its gluten is not as adequate for bread making as wheat; however, it is used to produce cookies, pastas and pizza dough and used in mixture with wheat flour for many other purposes. The crushed grains are used in mixtures in multigrain food and dietetic products.

Triticale is, however, mainly used in animal feed since it is produced in the winter, a period of low forage availability. Triticale is therefore transformed into meat, milk or eggs, giving producers the possibility to add value to their farm production.

Grain consumption for feed in Brazil has been based on maize (97 percent). The large distance between the main maize-producing centres, the reduced possibility for expansion of growing areas near the sources of demand and the yearly oscillation of price have induced the producers to seek alternative sources of energy and protein for feed. Triticale is grown during the winter season, while maize is a summer crop and is harvested in a period when historically the price of maize is high. This has permitted triticale to become a profitable alternative for farmers that have maize as a feed base. In addition, triticale has 3 to 4 percent more crude protein concentration than maize grain, which allows the farmer to reduce other protein sources, such as soybean meal in feed formulation, assisting in the reduction of animal production costs.

According to Baier *et al.* (1994), triticale received decisive support from the swine and poultry industries in Brazil in 1991. In that year, technicians from the industry were responsible for conducting and supervising dozens of on-farm demonstration plots, thus promoting triticale cultivation.

On small farms, triticale is used especially for direct feeding as green forage or as silage of young or mature plants, moist or dry grains, and hay. The nutritional quality of the silage is a function of the raw material. Whole-plant silage, using plants close to maturity, in general gives high protein and energy yield, but low digestibility of the silage. On the other hand, when young plants are used for silage, yield is low but the silage has a high protein content and better digestibility. To obtain high-quality silage, it is important that plants be chopped into pieces no larger than 1 cm long and the silage pile be tight and well closed and compacted. Since early-stage plants present lower levels of dry matter (15 to 20 percent) than recommended for silage (30 to 35 percent), it is necessary that plants be dried out in the field, which is not easy because of the low evaporation pressure usually observed during that period. Such conditions may extend triticale presence in the field, increasing the risk of plant decomposition (Lima *et al.*, 2001).

Grain silage possesses good digestibility and high energy and protein concentrations making such silage desirable for swine and cow feed. Grain silage is made when grains have about 65 to 70 percent dry matter. Grains are ground to facilitate compaction and fermentation (Lima *et al.*, 2001).

If the purpose of triticale production is direct feeding as pasture or soil coverage, the sowing can be done just after the soybean harvest in late March to May with genotypes having a longer life cycle. Despite the early sowing date, triticale has good tolerance to low temperature compared to other winter cereals. This characteristic gives triticale an advantage because it provides good-quality pasture during the winter period of June and July when limited forage is available in the field.

Work done at Embrapa (Empresa Brasileira de Pesquisa Agropecuária) Suínos e Aves, located in Concórdia (Santa Catarina), shows that triticale grain can economically substitute maize grain and soybean bran in the formulation of rations for swine (EMBRAPA, 1991). Other advantages of triticale, including high protein levels and good digestibility, make triticale a recommended alternative to feed young animals, but the low fat and energy levels give some disadvantage to triticale for terminal feed. Some anti-nutritional factors present in rye and in old triticale varieties were not detected in the Brazilian cultivars (Baier *et al.*, 1994).

It has been observed that the substitution of maize and wheat with triticale in rations for poultry and swine allows for a reduction in the amount of soybean bran in the diet due to the high levels of lysine found in triticale.

However, the low energy levels, in general, lead to an undesirable conversion in some cases.

The high lysine levels, high digestibility of crude protein, high phosphorus content and good mineral balance make triticale especially suitable for poultry and swine feed. In a study presented by Zanotto, Guidoni and Lima (1997), it was observed that during the animal life cycle, the substitution of maize with triticale led to a reduction in ration consumption and weight gain, except when diets constituted 75 percent maize substitution. The results were similar to diets in which maize was the major grain component. However, no difference was detected when animal feed conversion was studied. Considering the characteristics of animal carcass, bacon thickness and meat yield of swine, no difference was observed when comparing animals fed with triticale and animals fed with maize as the major energetic component. On the other hand, loin depth was larger at 25 to 50 percent substitution levels, and with 50 percent substitution level, the highest carcass yield was achieved. In general, it can be concluded that triticale can be used as much as 75 percent in substitution for maize in swine diets (from early growing to termination). The optimum economic level of substitution will depend on the price of each ration component and the market price for swine.

Wheat substitution with triticale in diets (0, 50 and 100 percent) for poultry resulted in proportionally lower performance in animals fed with increasing triticale proportion. This negative effect can be corrected with the addition of fat to increase energy levels in the diet. In the same way, supplementation of 0.5 percent of DL-methionine in diets containing triticale promoted weight gain in poultry when compared to poultry fed without an amino acid supplement (Brum *et al.*, 2000).

The use of triticale grain with low crude protein content requires attention with respect to amino acid content in diets. In some cases, it is necessary to add synthetic amino acids, such as methionine, lysine and threonine. The negative effect of the use of triticale with low crude protein content in substitution for other grains in diets for laying hens can be alleviated with the addition of crude protein in the diet, with no alteration to egg production (Lima *et al.*, 2001).

According to Brum *et al.* (2000), it is possible to substitute 75 percent of maize in diets using triticale without affecting the performance of poultry, weight gain, ration consumption and feed conversion.

CROP IMPROVEMENT

The major challenges for triticale breeding in Brazil are increasing grain yield potential, disease resistance, reducing sprouting, increasing nutritional value and improving adaptation to acid soils.

There are five institutions that have been working with triticale in Brazil: Brazilian Agricultural Research Corporation (Embrapa) at the National Wheat Research Center (Embrapa Trigo), Instituto Agronômico do Paraná (IAPAR), Fundação Centro de Experimentação e Pesquisa (FUNDACEP FECOTRIGO), Cooperativa Central Agropecuária de Desenvolvimento Tecnológico e Econômico Ltda. (COODETEC) and Instituto Agronômico de São Paulo (IAC). These institutions have triticale breeding programmes, basing their major germplasm variability sources on germplasm received from the International Maize and Wheat Improvement Center (CIMMYT) through the following nurseries: International Triticale Yield Nursery (ITYN), International Triticale Screening Nursery (ITSN), Facultative Winter Triticale (FWTCL) and some F_3 populations available at CIMMYT (Mexico).

At Embrapa Trigo, the triticale genetic breeding programme is focussed on obtaining triticales with specific characteristics for adaptation to local climates and on increasing genetic variability (Baier and Nedel, 1986). Rye, grown in Brazil for more than a century, has genetic characteristics that can be transferred to new varieties to promote adaptation. Natural selection may have contributed to the accumulation of favourable genes. Darvey (1986) suggests that the genetic base for today's triticales in the world is narrow and should be increased. This can also be applied to Brazilian varieties since all recommended cultivars came from a cooperation programme with CIMMYT.

Crosses of hexaploid triticale with octoploid triticale, rye or wheat are followed by back-crosses with hexaploid triticale to guarantee better efficiency and to restrict genetic variability. In back-crosses, pollen from F_1 plants is used due to its balanced number of chromosomes, which confers more viability (Varughese, Barker and Saari, 1987).

Resistance to *Gibberella* and foliage fungus must be improved and existing resistance to other diseases maintained. Two methods are used to evaluate *Gibberella* and to select genotypes: (i) inoculation of *Gibberella* into the spike in the field (Baier *et al.*, 1994); and (ii) a natural *Gibberella* nursery, with spore distribution and wetting of spikes from the heading stage onwards. *Gibberella* incidence, severity and number of grains with *Gibberella* symptoms are evaluated to detect initial infection resistance, subsequent colonization and expressed

TABLE 2
Most common varieties, pedigree, origin and commercial seed availability of triticale in Brazil, 2000-2002

Genotype[a]	Pedigree	Origin/Brazilian partner	Availability (*tonnes*)		
			2000	2001	2002
BRS 148	Yogui/Tatu	CIMMYT/Embrapa Trigo	76	1 247	1 398
BRS 203	LT-1/Rhino	CIMMYT/Embrapa Trigo	0	176	603
CEP 22-Botucaraí	BGL/CIN//IRA/BGL	CIMMYT/FUNDACEP	0	0	0
CEP 23-Tatu	BGL/3/MTZTCL/Wheat //BGL/4/Nutria	CIMMYT/FUNDACEP	944	262	77
CEP 28-Guará	Daman (Tatu4/ARD1)	CIMMYT/FUNDACEP	386	408	187
EMBRAPA 18	Tapir/Yogui//2*MUS	CIMMYT/Embrapa Trigo	1 222	1 377	331
EMBRAPA 53	LT1117.82/Civet//Tatu	CIMMYT/Embrapa Trigo	3 398	5 840	1 534
IAC 1 Juanillo	DRIRA//KISS/ARM	CIMMYT/IAC	-	-	-
IAC 2 Tarasca	TEJON/BGL	CIMMYT/IAC	-	-	-
IAC 3 Banteng	BANTENG "S"	CIMMYT/IAC	-	-	-
IAC 4	Tatu4/ARD1	CIMMYT/IAC	-	-	-
IAPAR 23-Arapoti	CIN/CNO//BGL/3/Merino	CIMMYT/IAPAR	2 741	3 440	1 202
IPR 111	ANOAS 5/STIER 13	CIMMYT/IAPAR	0	0	0
IAPAR 54-OCEPAR 4	URON	CIMMYT/IAPAR-OCEPAR	16	199	23
TRITICALE BR 1	M2A/CML	CIMMYT/Embrapa Trigo	0	0	0
TRITICALE BR 4	BGL/CIN//MUS	CIMMYT/Embrapa Trigo	672	707	48
Total	-	-	9 455	13 656	5 403

[a]Acronyms identify the Brazilian institution for genotype selection and/or recommendation: BR, BRS, EMBRAPA = Embrapa Trigo, Passo Fundo, Rio Grande do Sul; CEP = Fundação Centro de Experimentação e Pesquisa (FUNDACEP), Cruz Alta, Rio Grande do Sul; IAC = Instituto Agronômico de São Paulo, Campinas, São Paulo; IAPAR = Instituto Agronômico do Paraná, Londrina e Ponta Grossa, Paraná; OCEPAR = Cooperativa Central Agropecuária de Desenvolvimento Tecnológico e Econômico Ltda. (COODETEC), Cascavel, Paraná.

resistance in the grain (Lima and Fernandes, 2002).

Yield is evaluated simultaneously in high- and low-fertility soils to obtain genotypes that combine hardiness and high yield potential characteristics. The selection in low-fertility soils is carried out at sites that allow the identification of plants with tolerance to high aluminium concentration, low phosphorus availability and low nitrogen content. Soil liming is a common practice in Brazil, but aluminium-tolerant plants usually present a more vigorous and deeper root system. The efficiency of phosphorus and nitrogen uptake and utilization is a very important characteristic to seek in triticale breeding programmes in Brazil due to the existence of low-fertility soils and taking into consideration economic factors.

Before the promulgation of the law concerning cultivar protection in Brazil, all institutions involved in triticale breeding conducted Brazilian Triticale Trials in a cooperative way. The best genotypes of each institution were evaluated in a network of trials. Since the year 2000, trials are exclusive to each institution. With this new system, the number of environments tested has diminished, and the evaluation for adaptation is restricted to the testing area of each institution. It is possible that in the future more local cultivars will be available with specificity to certain environments rather than more broadly adapted genotypes.

Presently, there are 15 genotypes recommended in Brazil. In general, the ones that are more productive with broad adaptation and acceptance in the market are those that have more seed available for large-scale production (Table 2). Some of them do not have seed available for farmers except for the amount of seed required by law.

Seed production and certification follow international standards. In addition, each state has some extra specifications that increase quality, health and purity standards. Seeds are divided into classes: (i) genetic seed, which is produced and maintained by breeders; (ii) basic seed, which is an institutional responsibility; and (iii) registered, certified and inspected seed, which results from multiplication and is commercially distributed to farmers.

Some farmers chose to reduce production costs by using their own farm-saved seed. These seeds are normally produced without the rigorous control used during seed production, such as quality, purity and health. This practice makes it very difficult to standardize plant type and does not take advantage of the new and more productive genotypes developed by breeders.

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Production of triticale on the Canadian Prairies

D.F. Salmon

In 1953, the University of Manitoba, Winnipeg, began the first Canadian triticale (X *Triticosecale* Wittmack) breeding programme. Early breeding efforts concentrated on developing a high-yielding, drought-tolerant human food crop species suitable for marginal wheat-producing areas. In contrast, more recent programmes concentrate on developing improved animal feed and fodder varieties for production under a number of diverse environmental conditions. In recent years, triticale has seen a rebirth in interest from farmers in western Canada as a means of crop diversification. As a consequence, since 1990 triticale production has risen from approximately 10 000 ha to 100 000 ha.

In western Canada, all triticale varieties both public and private have been released after rigorous cooperative testing under the auspices of the Prairie Regional Recommending Committee on Grain (PRRCG). The PRRCG meets on an annual basis and forwards recommendations for registration to the Variety Registration Office of the Canadian Food Inspection Agency (CFIA). Since the registration of the first Canadian spring triticale variety Rosner (1969), a total of only 18 spring and winter varieties have been evaluated in western Canada and subsequently released (Table 1, Table 2). This process of registration is currently under review.

Triticale, unlike the major cereal crops such as barley and several classes of wheat, is not controlled by a marketing board system, such as the Canadian Wheat Board. Most of the production is utilized within the country for forage and as a feed crop as well as for some other minor-use industries. Limited amounts are exported to mills in the United States of America and for reproduction for grain and forage use.

SPRING TRITICALE

Performance

Under dryland conditions, spring triticales are a valuable alternative to feed barley and oats. Spring triticale has a 5 to 19 percent yield advantage (Table 3) over the high-yielding Canadian Prairie Spring wheat (CPS). This advantage is most apparent in areas with longer growing seasons (Figure 1), such as the brown soil zones of Alberta, Saskatchewan and Manitoba, due to the late maturity (Table 4) of most varieties (Salmon *et al.*, 2001).

Cultural practices

While the test weights and weight per 1 000 kernels of the various Canadian classes of wheat are very similar within classes, this is not true for triticale. In general, a spring triticale has a 1 000 kernel weight that is 20 percent greater than a Canadian Western Hard Red Spring wheat (CWRS) or just slightly greater than the CPS class. It is suggested that farmers not familiar with setting their seeding equipment for triticale use a minimum of 110 kg/ha of seed. This on average comes very close to the recommended plant population of 310 plants/m^2, which compensates for the fact that the spring triticales commonly grown on the prairies are not aggressive tiller producers.

The cultural techniques for growing spring triticale in any one production zone are generally very similar to those used for spring wheat. Consequently, the fertilization, seedbed preparation, seeding depth and seeding methods used for wheat are acceptable for triticale. The major difference between wheat, as well as other common cereal crops, and triticale is the fact that few pesticides are registered for use on triticale. However, it is common for producers to use chemicals that are suitable for use on wheat and rye.

WINTER TRITICALE

Performance

Winter triticales are best adapted to the brown and black soil zones of the prairies where there is adequate snow cover (15 cm) throughout the winter or snow trapping through the use of minimum tillage. Winter triticale performs very similarly to spring triticale but has the major advantage of three-week earlier maturity compared to its spring counterpart. Varieties such as Pika, and to a lesser extent Bobcat, are similar in winter hardiness to the best of the Canadian Western Hard Red Winter wheats and 10 to 20 percent higher yielding (Table 5). To date, the winter triticale varieties have not reached the level of hardiness found in winter rye (Table 6).

TABLE 1
Old and current spring triticale varieties, 1969-1999

Variety	Year	Institution[a]	Status
Rosner	1969	University of Manitoba	Deregistered
Welsh	1977	University of Manitoba	Deregistered
Carman	1980	University of Manitoba	Deregistered
OAC Triwell	1980	Ontario Agriculture College	Deregistered
Wapiti	1987	FCDC, AAFRD, Alberta	Registered
OAC Trillium	1988	Ontario Agriculture College	Deregistered
Frank	1988	Agriculture and Agri-Food Canada	Registered
Banjo	1991	University of Manitoba	Registered
AC Copia	1993	Agriculture and Agri-Food Canada	Registered
AC Alta	1994	Agriculture and Agri-Food Canada	Registered
AC Certa	1995	Agriculture and Agri-Food Canada	Registered
Pronghorn	1996	FCDC, AAFRD, Alberta	Registered
Sandro	1998	Swiss Fed. of Agric. Res.	Registered
AC Ultima	1999	Agriculture and Agri-Food Canada	Registered

[a]FCDC = Field Crop Development Centre; AAFRD = Alberta Agriculture, Food and Rural Development.

TABLE 2
Old and current winter triticale varieties, 1980-1999

Variety	Year	Institution	Status
OAC Wintri	1980	Ontario Agriculture College	Deregistered
OAC Decade	1984	Ontario Agriculture College	Deregistered
Pika	1990	Alberta Agriculture, Food and Rural Development	Registered
Bobcat	1999	Alberta Agriculture, Food and Rural Development	Registered

TABLE 3
Grain yield of spring triticale compared to Canadian Prairie Spring wheat (CPS), 1995-2000[a]

Variety	Soil zone				
	Black (%)			Brown (%)	Irrigation (%)
	Manitoba	Saskatchewan	Alberta		
Pronghorn	136	112	119	110	114
AC Alta	135	106	119	105	121
AC Ultima[b]	140	120	120	107	115
CPS wheat	100	100	100	100	100

[a]Data based on Prairie Regional Recommending Committee on Grain (PRRCG) and provincial adaptation trials.
[b]Limited number of station years compared to other varieties.

TABLE 4
Days to maturity of spring triticale compared to Canadian Prairie Spring wheat (CPS), 1995-2000[a]

Variety	Soil zone				
	Black (*days*)			Brown (*days*)	Irrigation (*days*)
	Manitoba	Saskatchewan	Alberta		
Pronghorn	97	107	123	109	102
AC Alta	103	111	132	114	105
AC Ultima	97	-	126	109	102
CPS Wheat	95	104	116	104	98

[a]Data based on Prairie Regional Recommending Committee on Grain (PRRCG) and provincial adaptation trials.

FIGURE 1
Soil zones of the Canadian Prairies

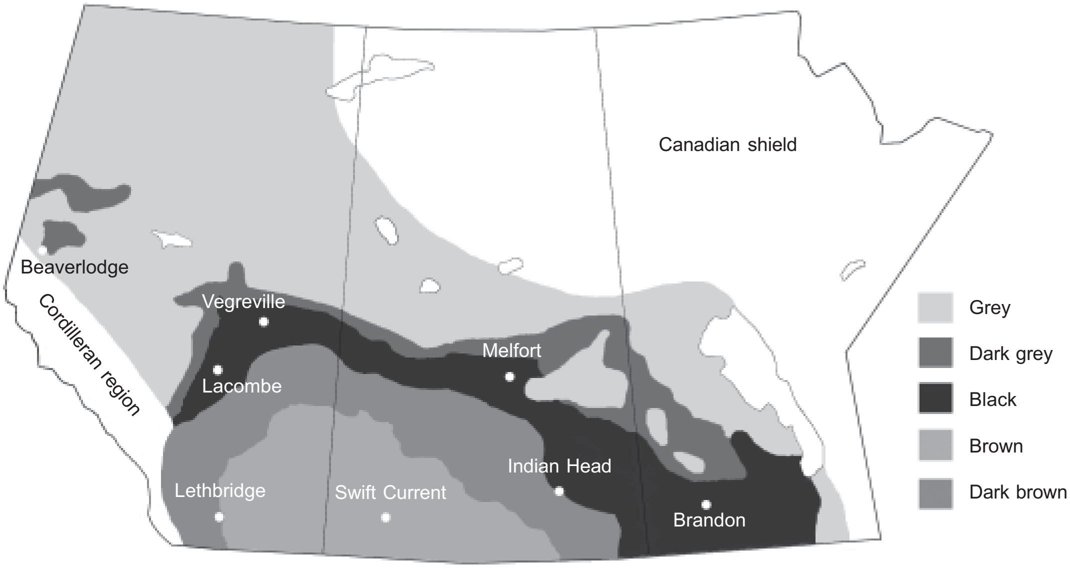

TABLE 5
Relative yield of winter triticale and rye compared to winter wheat CDC Osprey, 1995-2000[a]

Variety	Soil zone	
	Black (%)	Brown (%)
Bobcat	118	119
Pika	104	137
Musketeer[b]	100	105
CDC Opsrey	100	100

[a]Data based on Prairie Regional Recommending Committee on Grain (PRRCG) and provincial adaptation trials.
[b]Rye.

TABLE 6
Winter survival of winter triticale, rye and winter wheat CDC Osprey, 1995-2000[a]

Variety	Soil zone	
	Black (%)	Brown (%)
Bobcat	86	85
Pika	91	88
Musketeer[b]	90	91
CDC Osprey	84	80

[a]Data based on Prairie Regional Recommending Committee on Grain (PRRCG) and provincial adaptation trials.
[b]Rye.

Cultural practices

Planting densities in principle are the same for winter triticale as for spring triticale. However, since there is usually some winterkill during an average year, producers are encouraged to use at least 320 to 330 seeds/m^2. The recommended planting date for winter triticale is between the last week of August and the first ten days of September across the prairies (Jedel and Salmon, 1994). To ensure rapid emergence and adequate crown development, winter triticale as well as winter wheat is planted at a depth no greater than 2.5 cm.

The fertility requirements for winter wheat and triticale are quite similar. The development of modern minimum-tillage equipment with the capability of placing the fertilizer in bands near the seed has allowed for the placement of both the nitrogen and phosphate at seeding rather than broadcasting the nitrogen in the spring.

ABIOTIC AND BIOTIC STRESSES

The major abiotic stresses for spring and winter triticale are primarily those related to climate conditions. The relative short growing season restricts the production of spring triticale, and the severe winters impact on the production of winter triticale. Although there are significant saline as well as acid soils in parts of the prairies, these are not as serious a problem as in most other production areas around the world.

In a similar fashion, triticale has as yet not been impacted by severe biotic stresses. This is likely due to the fact that the crop has only recently reached a significant level of production. To date, triticale varieties have only low to moderate levels of wheat leaf diseases and few insect pests. The germplasm from the International Maize and Wheat Improvement Center (CIMMYT) used in most programmes has maintained excellent levels of leaf and stem rust resistance. The increasing levels of scab are expected to be a major concern in the near future.

UTILIZATION

Forage and fodder

Triticale provides an excellent alternative to and complements the production of barley silage. This is of significant importance in areas that have large populations of animals in feedlot situations. Heavy applications of animal manure and continuous cropping with barley have resulted in significant problems and a build-up of disease problems in the production fields. Spring triticale yields (Table 7) at least equal to and in many cases greater than conventional barley varieties and CPS wheat. Khorasani *et al.* (1997), studying the chemical composition of oat, barley, triticale and alfalfa, indicated that triticale was similar to barley for silage quality. This coupled with good lodging resistance and resistance to barley diseases has made triticale an important part of many large-scale silage operations.

Although winter triticale is used for the production of an early silage crop, it has had significant impact as a spring-seeded, long-season annual grazing crop. Spring-seeded (early May) winter triticale can be rotationally grazed beginning in late June until late November in years with adequate autumn moisture. This provides livestock producers with an inexpensive means of extending the grazing season and reducing the use of expensive conserved feed.

Livestock feed

Unlike in many other countries worldwide, the use of triticale as a feed grain has been somewhat limited. This has been due to the large quantities of feed barley and in many years downgraded spring wheat. However, work conducted by Jaikaran *et al.* (1998), which indicated that triticale fed to hogs resulted in growth and carcass quality similar to hulless barley and maize, has stimulated some interest in the utilization of triticale grain as a feed stock.

TABLE 7

Silage yields (dry matter) of spring triticale and Canadian Prairie Spring wheat (CPS) compared to Cascade spring oat, 1995-2000[a]

Variety	Stage	
	Anthesis (%)	Dough (%)
Pronghorn	114	109
AC Alta	113	103
AC Ultima	119	107
CPS wheat	96	81
Cascade[b]	100	100

[a]Data provided by the Field Crop Development Centre, Alberta Agriculture, Food and Rural Development, Lacombe, Alberta.
[b]Oat.

VARIETY IMPROVEMENT

Variety improvement in Canada has been mainly based on publicly funded programmes. To a large extent, the involvement of the private sector has been restricted to the marketing of varieties and products. The two current programmes at Agriculture and Agri-Food Canada (AAFC), Swift Current, Saskatchewan (spring), and at the Field Crop Development Centre (FCDC), Alberta Agriculture, Food and Rural Development (AAFRD), Lacombe, Alberta (spring and winter), are the principle players in variety development and improvement.

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Triticale developments in China

S. Yuanshu, W. Zengyuan

RESEARCH AND DEVELOPMENT OF TRITICALE

Triticale research in China started in the 1950s. The first varieties were initially tested across the country in 1970 and first released in 1976 (Wenkui, 1981). Triticale was mainly used as a food crop. Because of its resistance to diseases and good adaptation to harsh environments, triticale was planted mainly in high elevation and cold mountain areas in southwestern and northwestern China. More recently, with the new adjustment in agricultural structure, triticale began to be used as a fodder crop (Yuanshu, Yun and Zengyuan, 1996). Its production potential, particularly the biological yield and quality, was fully developed allowing it to become a dominant fodder crop around the country. Triticale planting area expanded to the Huang-huai-hai plain, south of the lower areas of the Yangtze River, and northeast to the mountain areas. In 2002, the area planted to triticale exceeded 300 000 ha and will increase in the coming years. A significant increase in area sown to triticale was noticed in 1980. The changes in triticale area in China from 1975 to 2003 are shown in Figure 1. The development of triticale in China experienced five phases (Yuanshu, 2002), which are described below.

Testing phase (1970-1975)

Triticale tests began in China in 1970. The yields of the first triticale varieties tested in mountain areas were higher than those of other crops. Compared to wheat, triticale yield increases varied from 9 to 23 percent. Multilocation tests of triticale varieties were carried out in the mountain regions of Guizhou province with an altitude of 1 700 to 2 600 m during the period 1972-1975. The yield tests showed that in eight out of ten locations triticale varieties were higher yielding than those of check crops including wheat and rye. The mean yield of triticale varieties tested was 2.5 tonnes/ha, representing a 41 to142 percent and 31 to 98 percent increase over wheat and rye, respectively. Among tested genotypes, Triticale No.2 and No.3 were the highest yielding. Their high grain yield of 1.5 tonnes/ha was mainly due to their high cold, disease and stress resistance. Wheat, in general, has very low yields in these regions due to its sensitivity to frost and hail. Therefore, the farmers in high elevation and cold mountain areas prefer to plant triticale. This resulted in a substantial increase of triticale area, which reached 733 ha in 1976.

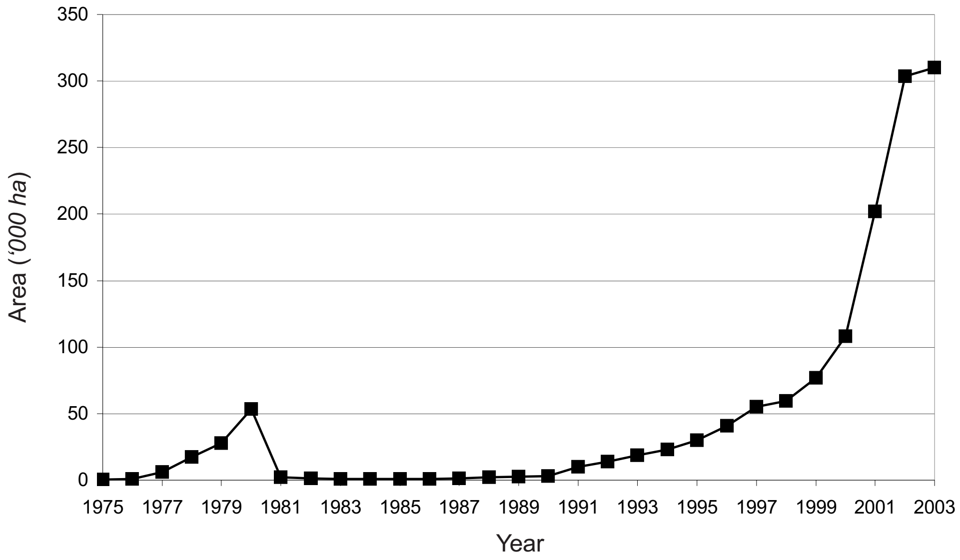
Expanding phase (1976-1980)

The first national meeting on triticale demonstration was held in Guizhou in June 1976. Scientific researchers and farmer delegates from 15 provinces attended the meeting. They visited the triticale fields and surveyed the crop growth state planted at different elevations, sowing date and cropping patterns; and they measured the triticale yields on site. The results showed that triticale mean yield was 3.5 tonnes/ha, which was 30, 40 and 50 percent higher than wheat, rye and oats yields, respectively. Following much promotion at the national level, the development of triticale was enhanced resulting in an extensive expansion of this crop around the country, and its area increased rapidly. Due to its cold resistance, good adaptation to poor soils, resistance to disease, good quality and its contribution to solve the urgent problem of food needs, octoploid triticale was quickly adopted in the Wumeng, Liang, Qinling, Dabian, Funiu, Liupan and Yin mountains. The triticale area recorded in 1977 at 5 866 ha suddenly increased substantially to reach 53 333 ha in 1980.

Decreasing phase (1980-1985)

Octoploid Triticale No.2 and No.3, which were developed by the Institute of Crop Breeding and Cultivation, Chinese Academy of Agricultural Sciences (CAAS), were the first group of varieties grown for demonstration around the country (Wenkui and Yurui, 1993). Their diverse characters, such as grain plumpness, plant height, maturity and cold resistance, were not fully satisfying, although they showed high seed fertility. These varieties could not perform well in some new areas with varying ecological environments. As a result, seeds were shrivelled, and therefore grain price was low in some areas. Hence, triticale area decreased dramatically from 53 333 ha in 1980 to 2 000 ha in 1981, and it stabilized at 866 ha in 1985. The rapid decrease in triticale area was similar to its initial increase during the expanding phase.

FIGURE 1
Change of triticale area in China, 1975-2003



Restoring phase (1986-1990)

Based on their findings, researchers found that triticale development and adoption was basically dictated by the adaptation of the varieties. For Triticale No.2 and No.3, which were the first-ever varieties released around the country, the agronomic characteristics were not generally satisfying, and the varieties were not adapted to various ecological environments. Therefore, researchers began to adjust their triticale breeding goals from selection for food crop uses only to food, fodder and food-fodder dual-crop types. Special attention was paid to varieties adapted to specific areas. Recurrent selection techniques were applied in addition to normal family selection. As a result, various variety types, such as octoploid, hexaploid and substituted lines, were selected (Yuanshu and Chongyi, 1986). The new varieties generated were better adapted to various ecological environments. Jingsong No.8, Jingsong No.49, Qianzhong No.1 and Qianzhong No.2 adapted well to the Wumeng mountain area, whereas Zhongqin No.1 and Zhongqin No.2 were adapted to the Qinling mountain area. Triticale No.81-14 and Zhongxin No.1881 were better adapted to Inner Mongolia. This enhanced triticale adoption since it became better adapted to local ecological environments and could meet the market requirements of most regions. Therefore, triticale area began to increase again and reached 3 400 ha in 1990.

Development phase based on market requirements (1991-present)

In recent years, the agricultural structures in China have changed. The food-economic cropping system is being substituted with a food-economic-fodder cropping system because fodder crops are insufficient in the country while food and economic crop production is sufficient. Triticale is promising as a high-output potential crop for food and fodder that can be planted either in winter or spring due to its fast vegetative growth, high biological output and good nutritive quality. Therefore, triticale has been given another chance for production around the country. Recently, newly developed varieties have been bred for different desirable traits following adjustments in breeding objectives. These cultivars include: fodder types Zhongsi No.237 and Zhongsi No.1890; food-fodder types Zhongxin No.830 and Zhongxin No.1881; and food types Jinsong No.49, Qianzhong No.3 and Xinjiang Triticale No.1. The fresh-matter yield of the newly developed fodder-type variety is about 37.7 to 45 tonnes/ha, while dry-matter yield is about 10 tonnes/ha. Grain yield of the food-type variety is about 3 to 4 tonnes/ha. High biological yield and good adaptation of the new varieties have resulted in a significant increase in area of triticale in the country, reaching 10 066 ha in 1991, 108 000 ha in 2000 and 303 333 ha in 2002, a substantial increase compared to triticale areas in 1991. Most triticale is used for animal feed (Table 1).

TABLE 1
Total area grown to triticale food and fodder in China, 1975-2002

Type	1975		1980		1985		1990		1995		2000		2002	
	Area (*ha*)	Type (*%*)	Area (*ha*)	Type (*%*)	Area (*ha*)	Type (*%*)	Area (*ha*)	Type (*%*)	Area (*ha*)	Type (*%*)	Area (*ha*)	Type (*%*)	Area (*ha*)	Type (*%*)
Food	467	100	53 333	100	866	100	10 000	99.3	29 000	96.7	12 000	11.1	12 666	4.3
Fodder	0	0	0	0	0	0	66	0.7	1 000	3.3	96 000	88.9	290 667	95.7
Total	467	100	53 333	100	866	100	10 066	100	30 000	100	108 000	100	303 333	100

DISTRIBUTION AND PRODUCTION AREAS OF TRITICALE

In the early stages of triticale development, triticale was mainly planted in the cold mountain areas in southwestern and northwestern China, where the environmental and production conditions are difficult and where low temperature, poor soil and bad economic conditions prevail. Triticale normally performs well and produces satisfactory yield in these areas due its cold and other stress resistance. Therefore, farmers in these areas planted triticale extensively. With the adjustments in agricultural structure in China in the 1990s, triticale began to be used as a fodder crop and showed high potential. Recently, triticale has expanded to the Huang-huai-hai plain, south of the lower areas of the Yangtze River, and to northeastern China. At present, triticale is becoming a dominant crop in the country.

Triticale in southwestern and northwestern China

The topography and climate in high elevation and cold mountainous areas in southwestern and northwestern China are very complex. Farmers in these regions have adopted specific crops and different cropping systems. In order to promote triticale in these areas, it is very important to demonstrate the technical and environmental feasibility and the economic viability of the cropping system based on local conditions.

Areas with one crop per year

These regions include the following areas: Yin mountain, with an elevation of 800 to 1 000 m and fall sowing; Liupan mountain, with an elevation of 1 000 m; Funiu mountain, with an elevation of 800 to 1 000 m; Qinling mountain, with an elevation of 1 000 to 2 500 m; Daba mountain, with an elevation of above 1 000 m; Liang mountain, with an elevation of 2 000 to 2 300 m; and Wumeng mountain, with an elevation of 2 400 to 3 000 m. The similarities between these areas are high elevation, low temperature and a harsh climate. The annual mean temperature is about 2° to 8°C, and the frost-free period is about 150 days. Crop yields with a long growth period in these areas are 3 to 4 tonnes/ha. Triticale is generally planted between the end of August and early October and harvested in July except for the spring-sowing area. The growth period of the crops in these areas is between 270 and 320 days.

The environmental and climatic conditions in these areas are difficult, often affecting crop yield because of drought, late frost, or acid or poor soil. Triticale often resists or avoids these stresses and those caused by diseases, particularly scab. Therefore, the yield of triticale in these areas is much higher than other crops, averaging about 1.5 to 2 tonnes/ha, allowing triticale to become a promising crop with high and stable yield for this region.

Areas with two crops per year

These areas are characterized by an elevation of 800 to 2 000 m, an average temperature of 12° to 16°C and a frost-free period of 200 to 250 days. The average temperature in these areas usually increases gradually with a decrease in elevation. Based on average temperatures, this region can be divided into areas with a mean temperature above 14°C (successive cropping area) and areas with a mean temperature below 14°C (intercropping area).

The successive cropping area has high solar radiation where triticale shows a longer growth period compared to wheat. However, there is enough time for other crops, such as maize and sweet potato, to reach high yields when grown after triticale.

The intercropping area includes the transitional region between areas with one crop per year and areas with two crops per year. The characteristics of this area are cold climate, mean temperature between 10° and 14°C and a cropping system with two crops per year. Triticale is normally intercropped with high-yield crops, particularly potato and maize.

Areas with three crops per two years

These areas with three crops per two years are the transitional areas located between areas with one crop and two crops per year. These areas have an elevation of 2 000 to 2 400 m. Normally, triticale could not be planted because of cold climate and delayed harvest. However, in this region triticale fits easily in the following cropping sequences: triticale-fall buckwheat-potato, triticale-fall potato-early buckwheat, or triticale-soybean-potato.

Triticale cultivation in the Huang-huai-hai plain and southern lowlands

Successive cropping in the Huang-huai-hai plain

The Huang-huai-hai plain is the largest production area for winter triticale. The accumulated sunshine hours per year are between 2 000 and 2 800 hours, and average temperature is 11° to 15°C, with an accumulated temperature above 10°C (base temperature) of 3 600° to 4 800°C d. It has a frost-free period of 170 to 240 days. The major cropping system is two crops per year. Soils both upland and lowland are fertile with excellent irrigation facilities. Although some areas north of the Yellow River receive less rainfall, most of the fields could be irrigated giving high yields. Therefore, the Huang-huai-hai plain is the main production area for food and cotton in China. The most dominant cropping systems include triticale-maize, triticale-rice and triticale-cotton.

Multiple cropping in the southern lowlands

These areas have much more solar radiation than the Huang-huai-hai plain. The accumulated temperature above 10°C is about 4 600° to 5 600°C d, and the number of frost-free days is 230. Therefore, the main crops cultivated in this area are wheat, maize, rice, peanut and soybean. Because of high rainfall during the growing period and the irrigation facilities available, crop yields are always high. These areas are, therefore, the main production source for food and oil crops in China. Since triticale has shown high yield, good quality, resistance to scab and it can be planted in winter, it has become a new dominant crop in this area.

UTILIZATION PATTERNS OF TRITICALE

Triticale end-uses have been changing with the increase of triticale adoption in China. Before 1995, it was mainly used as a food crop in high elevation and cold mountain areas. With social improvements and adjustments in the agricultural structure, triticale breeding objectives have shifted from single use for food type to multiple uses including fodder, food-fodder and dual-purpose types.

Before 1990, almost all triticale was used for food. After 1990, the use of triticale began to change from food to fodder. As a result, fodder triticale started to expand significantly in the following years. The area of fodder triticale in 1995 was only 3.3 percent; it then increased to 88.9 percent in 2000 and reached 95.7 percent in 2002. The trend of agricultural structure adjustment is reflected by the change in triticale area and uses. Subsequently, triticale areas began to expand to the Huang-huai-hai plain, Tianjin and Tangshan. On-farm demonstration results show that triticale will expand to the lowlands in southern China and to the northeastern and northwestern areas of China.

NEWLY RELEASED TRITICALE VARIETIES

From 1976 to 1993, triticale was mainly used as a food crop to resolve food problems for farmers in high elevation and cold mountain areas in southwestern and northwestern China. In recent years, fodder triticale has developed quickly in China, which has promoted the development of animal husbandry. The major triticale varieties with a large planting area in China are described in Table 2.

TRITICALE RESEARCH INSTITUTIONS

The national and regional research institutions working on triticale in China are: the Institute of Crop Breeding and Cultivation, CAAS; Crop Research Institute of Guizhou Academy of Agricultural Sciences; Agricultural College of Xinjiang Shihezi University; and the Northeast Agricultural University. A national triticale research network coordinated by the Institute of Crop Breeding and Cultivation, CAAS, was formed in the 1970s in order to improve triticale breeding efficiency, shorten the time for variety development and promote triticale. The major tasks of the triticale research network are described below.

Development of new varieties

Triticale is a new crop that lacks genetic diversity. To breed improved varieties different in their genetic construction was the first target of the network. The Chinese Academy of Agricultural Sciences was the first institution in China to start working on triticale. The long experience in triticale breeding by CAAS has allowed this institute to create and accumulate more triticale breeding material than other institutions. Therefore CAAS offered the breeding materials and breeding technology to the network members to help them establish efficient breeding programmes. Following selection within this material, new varieties adapted to different ecological

TABLE 2

Cultivar names, year and institution of release, and main agronomic characteristics of triticale

Cultivar	Year and institution of release[a]	Main characteristics
Triticale No.2	1976; CAAS	Octoploid; adapted but no winter hardiness; average tillering; 1 000 kernel weight = 40 g; 80% seed fertility; average plumpness; 16.1% protein content; resistant to powdery mildew and rusts; medium resistant to scab; used for food
Triticale No.3	1976; CAAS	Octoploid; adapted but no winter hardiness; height 140 cm; medium tillering and maturity; 1 000 kernel weight = 45 g; 80% seed fertility; 16.3% protein content; resistant to powdery mildew and rusts; medium resistant to scab; used for food
Zhongla No.1	1985; CAAS	Octoploid; spring habit; height 125 cm; medium tillering and maturity; 1 000 kernel weight = 30 g; 80% seed fertility; average plumpness; 16.9% protein content; resistant to powdery mildew and rusts; medium resistant to virus diseases; used for food
Zhongxin No.1881	1988; CAAS	Hexaploid; spring habit; height 140 cm; medium tillering and maturity; 1 000 kernel weight = 35 g; 80% seed fertility; average plumpness; 16.9% protein content; resistant to powdery mildew and rusts; medium resistant to virus diseases; used for food and fodder
Zhongqin No.1 and No.2	1991; CAAS	Hexaploid; winter hardy; height 130 cm; medium tillering and early maturity; 1 000 kernel weight = 35 g; 86-87% seed fertility; average plumpness; 16.9% protein content; resistant to powdery mildew and rusts; used for food
Zhongsi No.1890	1992; CAAS	Hexaploid; winter hardy; height 150-170 cm; medium tillering and maturity; 1 000 kernel weight = 38 g; 88% seed fertility; 15.8% protein content; resistant to powdery mildew and rusts; used for fodder
Zhongxin No.830	1993; CAAS	Hexaploid; adapted but no winter hardiness; height 140-160 cm; medium tillering and maturity; 1 000 kernel weight = 45 g; 89% seed fertility; average plumpness; 15.4% protein content; resistant to powdery mildew and rusts; used for food and fodder
Jinsong No.49	1995; CAAS	Octoploid; adapted but no winter hardiness; height 122 cm; medium tillering and early maturity; 1 000 kernel weight = 42 g; 85% seed fertility; average plumpness; resistant to powdery mildew and rusts; medium resistant to scab; used for food
Qianzhong No.3	1998; CAAS	Octoploid; adapted but no winter hardiness; height 105 cm; medium tillering and maturity; 1 000 kernel weight = 41 g; 80% seed fertility; average plumpness; resistant to powdery mildew and rusts; medium resistant to scab; used for food
Zhongsi No.237	1998; CAAS	Hexaploid; winter hardy; height 150-170 cm; medium tillering and maturity; 1 000 kernel weight = 45 g; 89% seed fertility; 15.9% protein content; resistant to powdery mildew and rusts; used for fodder

[a]CAAS = Chinese Academy of Agricultural Sciences.

zones were developed and released by the triticale network in a short time. These included: Zhongla No.1 adapted to the eastern area of Inner Mongolia; Zhongqin No.1 and No.2 targetted for the Qinling mountain area; Qianzhong No.2 and No.3 for the Giuzhou province; Xinjiang No.1 for the Xinjiang Uygur autonomous region; and Zhongxin No.830, Zhongxin No.1881, Zhongsi No.1890 and Zhongsi No.237 with wide adaptation around the country (Table 2).

Improvement of breeding methodologies

Through a collaborative research effort among the network members, the breeding efficiency of triticale was enhanced greatly. In addition, the Chinese Academy of Agricultural Sciences (CAAS) successfully transferred the dominant male sterile gene (*MS2*) from wheat into triticale allowing triticale to be used as a cross-pollinated crop. A set of recurrent selection cycles has accelerated the improvement of triticale characteristics. As a result, time for developing triticale varieties was shortened and breeding efficiency was improved.

Varietal testing in various regions

Since its creation, the national triticale network has organized four rounds of varietal tests including both winter triticale varieties and spring triticale varieties. More than 20 varieties adapted to different ecological environments have been approved for promotion and growth around the country by both state and provincial committees. The newly released varieties have helped substantially the promotion and expansion of triticale in China.

Development of new triticale products

Triticale was initially used to make steamed bread, pancakes and noodles by farmers in the mountain areas. In recent years, triticale has been extensively used as fresh fodder, silage and hay in the Huang-huai-hai plain. Recently, triticale has also been used to make beer, alcohol and other drinks. The straw of triticale has been used to weave and to make dry flowers. The extension and development of triticale has promoted the comprehensive utilization of this crop.

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Triticale in France

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The production of triticale began in France in the early 1980s. It was mainly grown in two areas where animal breeding was dominant. These regions are: (i) Massif Central, a semi-mountainous region in the centre of France where frost resistance is important; and (ii) Bretagne and Pays de Loire, regions in western France with some hydromorphic soils and very high disease pressure.

The cultivation of triticale has expanded to other regions of France as shown in Figure 1 (ITCF, 2000). From the beginning, the area of triticale has increased continuously, reaching around 266 000 ha in 2002 (SEDIS, 2002a). Figure 2 shows the evolution of triticale and rye area from 1980 to 2001. Triticale still remains a secondary cereal compared to bread wheat with an area between 4.5 and 5 million ha for the same period[1]. However, triticale tends to replace rye in its traditional production area, i.e. in soils where wheat is not adapted and performs poorly. Triticale also has been replacing winter barley in western France.

The average yields of the main cereal species cultivated in France are shown in Table 1. The highest average yield was obtained for bread wheat, but it should be noted that triticale is mainly grown in marginal areas compared to wheat, which is usually grown on the best soils.

The French imports and exports of triticale are insignificant. The handling of triticale was about 4.5 million tonnes in 1998 (about one-third of the total production) (ITCF, 2000). However, there is a small local market in western France.

TRITICALE PRODUCTION AND MANAGEMENT

The soil and climate conditions are very different in the two regions, Massif Central and Bretagne, where triticale is mostly grown (Figure 1). Therefore, specific adaptation is required for cultivars to be released. In the Massif Central, triticale is mainly grown in semi-mountainous conditions (altitude 800 to 1 200 m). This requires early sowing (i.e. late September to early October). The varieties must be winter hardy, with good frost resistance. They should not be too early-heading in order to avoid late frost causing sterility. However, they should not be too late in order to be harvested before September. The main disease in this area is Septoria nodorum blotch.

In western France, the mild and rainy winters and springs favour the development of diseases. Therefore, the triticale cultivars released must be resistant to diseases, such as Septoria nodorum blotch, scab, leaf rust, stripe rust and eyespot, which are the most damaging pathogens in this region. In some parts of this region, good adaptation to hydromorphic soils and rainy weather is necessary. In such areas, the yield potential of triticale is greater than that of barley. In addition, the varieties with better resistance to pre-harvest sprouting are appreciated in this area. It is also very important to have varieties resistant to lodging.

Over the last few years, triticale area has also increased in some intensive cereal cultivation areas because it is more tolerant to take-all disease compared to wheat when grown in ‘cereal after cereal’ crop rotation. Until recently, triticale has been resistant to powdery mildew, but since 2000 some varieties have become very susceptible to this disease in France.

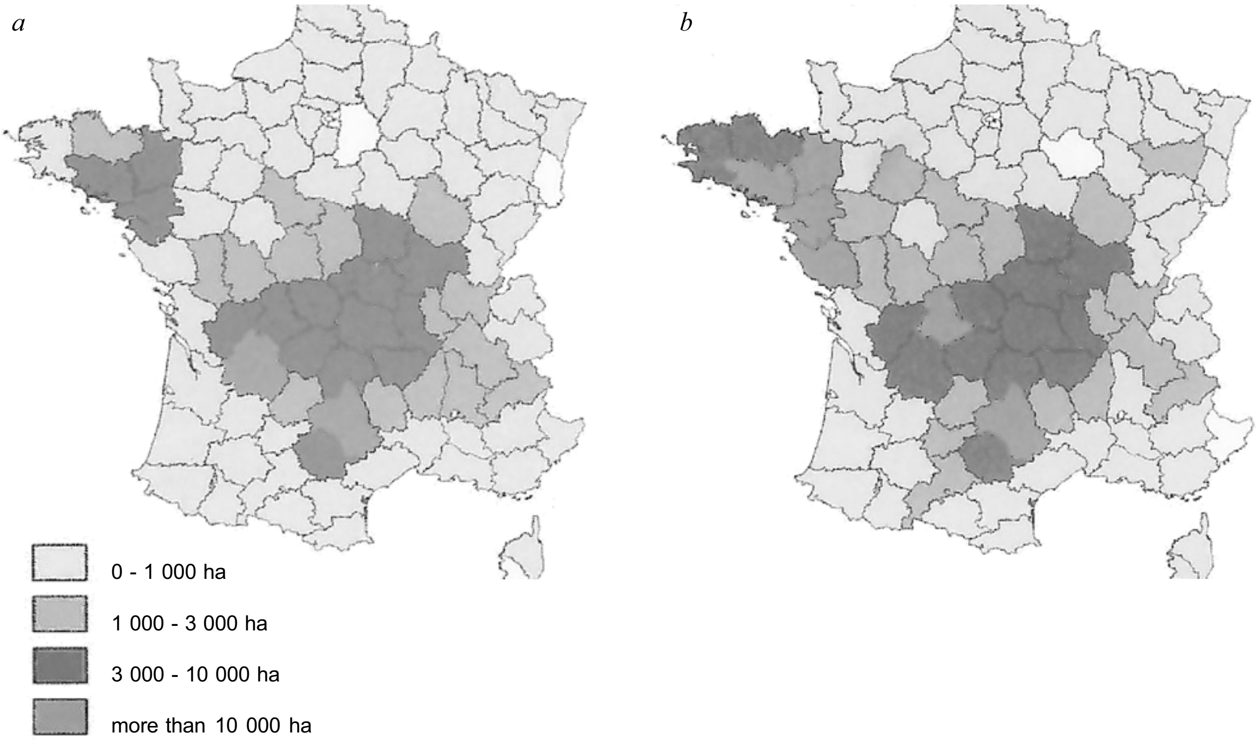
Another problem, due to an insect named Geomyza, which causes the death of plants during spring, appeared recently mainly in western and northern France. Triticale seems to be more frequently attacked than wheat by this insect. The weather conditions (cold period in spring) seem to play an important role. A difference in growth habit (more prostrate leaves at the time of hatching) may make triticale more attractive than wheat to the insects looking for a place to lay their eggs.

TRITICALE USES

Triticale in France is mainly used for animal feeding. Most triticale production is consumed directly on the farm for animal feeding, mainly for cattle. With a protein content between that of wheat and rye and more lysine than wheat, triticale can be used as well as wheat for cattle, pigs, poultry, rabbits and lambs. The low availability of triticale on the grain market is probably limiting its use by the

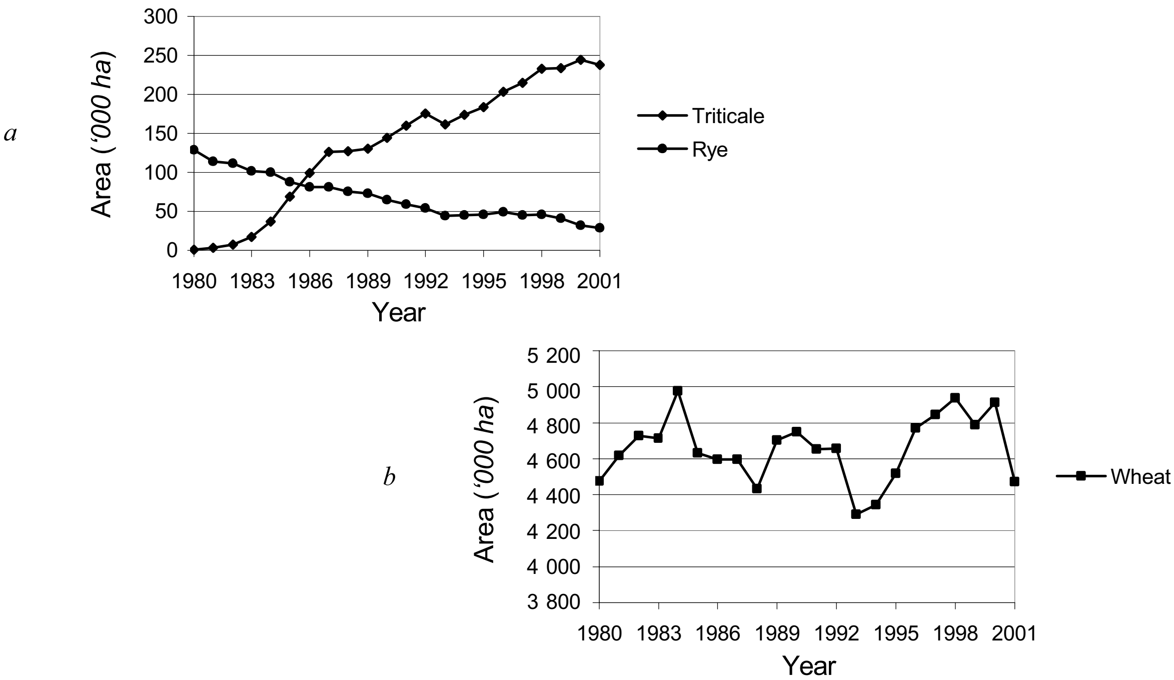
[1] Data from Statistique Agricole Annuelle and the Central Service of Statistical Surveys and Studies (French Ministry of Agriculture).

FIGURE 1
Evolution of triticale cultivation areas in France, 1989 (a) and 1997 (b)



Source: ITCF.

FIGURE 2
Area of triticale and rye (a) and wheat (b) in France, 1980-2001



Source: Data from Statistique Agricole Annuelle and the Central Service of Statistical Surveys and Studies (French Ministry of Agriculture).

TABLE 1
Average yield for main cereal species in France, 2000

Cereal species	Average yield (*tonnes/ha*)
Bread wheat	7.26
Winter barley	6.62
Triticale	5.17
Spring barley	5.67
Durum wheat	4.96
Rye	4.61

Source: SEDIS, 2002b.

feed processing industry in France. The development of this use depends mainly on the increase in area of this crop. This will be achieved only when the income provided by triticale is at least as high as that from wheat crops. New high-yielding varieties will be the key to taking up this challenge. The farmers who use straw for animal litter also appreciate the higher straw production of triticale compared to wheat. The use of triticale as forage, silage or for dual purpose is not very widespread in France.

Some companies have tried to develop the use of triticale for human food, in particular through bread making. It has been shown that, using special bread-making methods, quite valuable bread can be made with pure triticale flour. However, this use has remained very limited until now. As an anecdote, the authors can also report the use of triticale as a support for the mycelia multiplication of Paris mushrooms (ITCF, 2000).

TRITICALE IMPROVEMENT

During the period 1983-2001, 61 varieties were released (Table 2). More than half (34) were developed by French breeders. Some foreign companies also have subsidiaries working on triticale in France, such as Lochow-Petkus (Germany) or Svalöf-Weibull (Sweden). Other varieties from foreign countries were also released in France, mainly from Poland (seven varieties), but also from Switzerland (four varieties including two hybrids and five co-obtentions with French breeding companies), Germany (seven varieties) and the United Kingdom of Great Britain and Northern Ireland (two varieties). HybriTech and Dupont-Hybrinova have released three F_1 hybrid varieties of triticale (Kador and Clint from HybriTech in 1998 and 1999 and Hyno-trical from Hybrinova in 2001). However, these hybrid varieties have never been marketed because the hybridization chemical agents (Genesis and Croisor, respectively) used to produce these hybrids only have a provisional approval for wheat but not for triticale. The utilization rate of certified seed for triticale in France is 71 percent (in 1999), higher than wheat (59 percent) (SEDIS, 2002c). The evolution in time of seed multiplication area for the most cultivated varieties is reported in Figure 3.

The first triticale varieties registered in France were very tall, which made them susceptible to lodging. They were also difficult to thresh and their grain was shrivelled. Hence, breeders focussed on these traits, and modern varieties are improved for these characters. The triticale cultivar Clercal was tall, difficult to thresh and rather susceptible to pre-harvest sprouting. Lasko, the winter triticale cultivar, was also tall, but more resistant to frost and easier to thresh. Newton was even taller, but had higher productivity. Trimaran had combined higher productivity, resistance to lodging and easy threshing, which explains its widespread use. Most varieties available now are easy to thresh and many are resistant to lodging, such as Indian, Kortego, Tricolor, Galtjo, Trimaran, Ampiac and Carnac. Ampiac is one of the shortest varieties. However, triticale varieties grown in France, except for Tridel, Zeus and Rotégo, are still not very resistant to pre-harvest sprouting. Disease resistance has also been improved in triticale. Many varieties have a good level of resistance to eyespot coming from rye, but the problem of the stability of resistance has to be considered as well. The average resistance to scab in triticale is higher than in wheat, and most of the varieties have a good level of resistance to rusts. With these characters, triticale has been adopted in low-input farming, especially in areas where a low use of fungicides is common. For this reason, the interest in triticale from organic farming groups is increasing.

Due to the prevailing use of triticale in animal feeding, quality traits, such as protein content, viscosity related to arabinoxylans and phytase activity, now also have to be considered in breeding programmes (Genthon, 1997; Bouguennec *et al.*, 1998; Bouguennec, Oury and Jestin, 2000).

ROLE OF PRIVATE AND PUBLIC INSTITUTIONS IN TRITICALE IMPROVEMENT

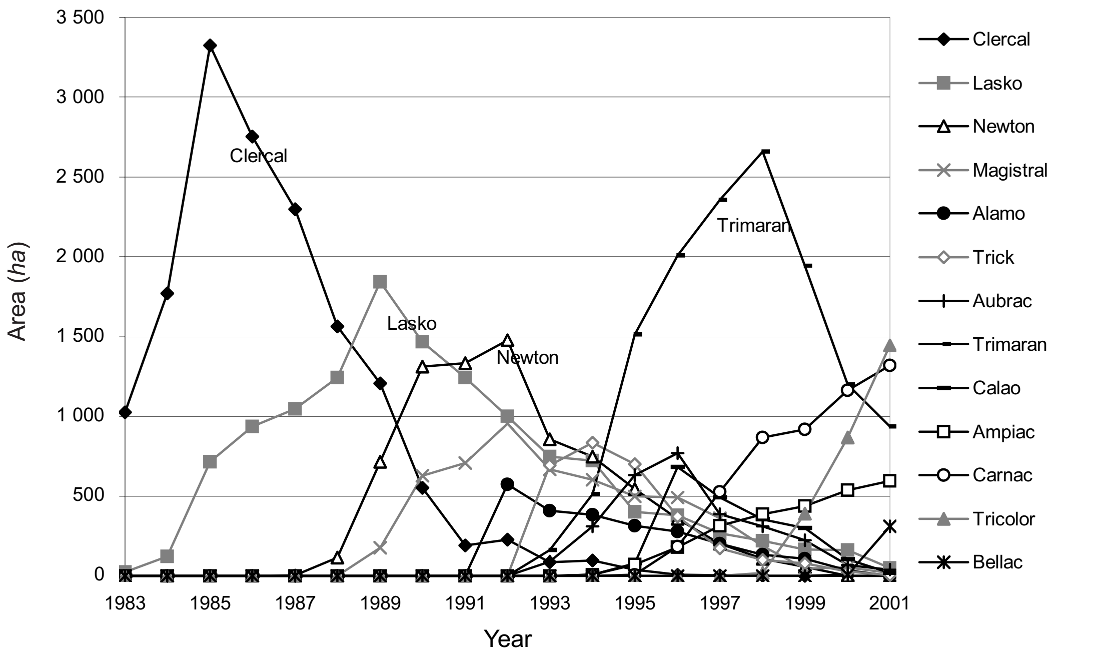
The National Institute for Agricultural Research (INRA) was the first institution to start working on triticale in France. In 1983, this institute registered the first French variety Clercal in the French official catalogue of cultivated varieties. After a few years, the increase in triticale area incited some private breeding companies to initiate a triticale breeding programme. The attraction of

TABLE 2
Triticale varieties released in France, 1983-2001

Variety	Year of release	Breeder and country
Clercal	1983	National Institute for Agricultural Research (INRA), France
Lasko	1983	Dankow-Laski, Poland
Newton	1987	Plant Breeding Institute Cambridge, United Kingdom of Great Britain and Northern Ireland
Dagro	1988 (struck off)	Poznan PB, Poland
Magistral	1988	National Institute for Agricultural Research (INRA), France
Gaétan	1989	Station de Changins, Switzerland / Orsem, France
Torpédo	1989	Serasem, France
Central	1990 (struck off)	National Institute for Agricultural Research (INRA), France
Domital	1990 (struck off)	National Institute for Agricultural Research (INRA), France
Alamo	1991	Poznan PB, Poland
Spatial	1991 (struck off)	C.C. Benoist, France
Trick	1991	Serasem, France
Aubrac	1992	RAGT, France
Trimaran	1992	Desprez, France
Tropic	1992 (struck off)	Serasem, France
Colossal	1993	National Institute for Agricultural Research (INRA), France
Formulin	1993	Orsem, France / Station de Changins, Switzerland
Graal	1993 (struck off)	C.C. Benoist, France
Olympus	1993	Semundo, United Kingdom of Great Britain and Northern Ireland
Brio	1994	DuPont-Hybrinova, France / Station de Changins, Switzerland
Calao	1994	National Institute for Agricultural Research (INRA), France
Ego	1994	Svalöf-Weibull, Sweden
Orbital	1994 (struck off)	C.C. Benoist, France
Ampiac	1995	RAGT, France
Falko	1995	Svalöf-Weibull, Sweden
Galtjo	1995	Svalöf-Weibull, Sweden
Mostral	1995	National Institute for Agricultural Research (INRA), France
Origo	1995	Svalöf-Weibull, Sweden
Carnac	1996	RAGT, France
Indiana	1996	DuPont-Hybrinova, France / Station de Changins, Switzerland
Arc-en-ciel	1997	Lemaire-Deffontaines, France
Chrono	1997	Danko Roslin, Poland
Disco	1997	Danko Roslin, Poland
Tridel	1997	Station de Changins, Switzerland
Vision	1997	Lochow-Petkus, Germany
Zeus	1997	RAGT, France
Capital	1998	National Institute for Agricultural Research (INRA), France
Imola	1998	DuPont-Hybrinova, France / Station de Changins, Switzerland
Janus	1998	Nordsaat Saatzucht, Germany
Orell	1998 (struck off)	Sudwestsaat, Germany
Rotégo	1998	Svalöf-Weibull, Sweden
Triathlon	1998	Florimond-Desprez, France
Trinidad	1998	Dr Hege, Germany
Kador	1998	Station de Changins, Switzerland
Tricolor	1998	Florimond-Desprez, France
Clint	1999	Station de Changins, Switzerland
Lamberto	1999	Danko Roslin, Poland
Lupus	1999	Nordsaat Saatzucht, Germany
Partout	1999	Dr Hege, Germany
Bellac	2000	RAGT, France
Kortego	2000	Svalöf-Weibull BV, Netherlands
Magnat	2000	Danko Roslin, Poland
Osorno	2001	Lochow-Petkus, Germany
Timbo	2001	Station de Changins, Switzerland
Auriac	2001	RAGT, France
Bienvenu	2001	Lemaire-Deffontaines, France
Cedro	2001	Svalöf-Weibull BV, Netherlands
Hyno-trical	2001	Dupont-Hybrinova, France
Passo	2001	Saaten Union recherché, France
Triade	2001	Florimond-Desprez, France
Trouvère	2001	Serasem, France

Source: Catalogue officiel des espèces et variétés, GNIS (1996-1998-2001) and Bulletin des variétés, GEVES (from 1986 to 1999).

FIGURE 3
Seed production area for official control of triticale varieties, 1983-2001



Source: SEDIS, 2002d.

TABLE 3
French public and private research institutions and their main triticale cultivar releases

Breeder	Year and name of first variety released[a]	Other varieties released (up to 2001)[a]
INRA[b]	1983, Clercal	Magistral, Central, Domital, Colossal, **Calao**, Mostral, Capital
RAGT (R2n)	1992, Aubrac	**Ampiac**, **Carnac**, Zeus, **Bellac**, Auriac
Florimond-Desprez	1992, **Trimaran**	Triathlon, **Tricolor**, Triade
C.C. Benoist	1993, Graal	Orbital, Spatial
Serasem	1989, Torpédo	**Trick**, Tropic, Trouvère
Lemaire-Deffontaines	1997, Arc-en-ciel	Bienvenu

[a]Varieties used as a control, i.e. the three varieties with the largest seed production area within a year, are indicated in bold.
[b]INRA = National Institute for Agricultural Research. This is a public institute.
Source: Catalogue officiel des espèces et variétés, GNIS (1996-1998-2001) and Bulletin des variétés, GEVES (from 1986 to 1999).

this new species was accentuated because triticale growers have a tendency to use more commercial seed than wheat growers. The main private companies that have a triticale breeding programme are presented in Table 3. In 1996, the five most important companies working on triticale (Table 3) merged their efforts in an economical interest group named GIE triticale in order to improve the breeding efforts on triticale. A joint programme has been developed with INRA for increasing genetic diversity of triticale (Bouguennec *et al.*, 1998). The National Institute for Agricultural Research produces new primary triticales (mainly octoploids from bread wheat and rye and some hexaploids from durum wheat and rye), crosses them with adapted triticale and the offsprings are advanced to the F_5 generation. The F_5 families are then evaluated by all partners, including INRA and GIE triticale, in order to find some interesting parental lines or even varieties.

CONCLUDING REMARKS

The pioneering work of INRA to develop triticale in France has been successful. Now, triticale is a 'traditional' crop in two regions of France, and private breeding companies play a major part in the development of new varieties. The narrow genetic basis of triticale, especially for the R genome from rye, is now enlarging thanks to cooperative work between private and public institutions. The first lines derived from this work are very promising. This will certainly induce the exploitation of primary triticale and advance new improved varieties, which will enhance the extension of triticale in France. Increasing area will perhaps provide greater availability of triticale grain for industries and consequently increase triticale use in France.

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Triticale in Germany

G. Oettler

The first fertile wheat x rye hybrid worldwide was produced by the German plant breeder Rimpau in 1888. He crossed a *Triticum aestivum* with rye and by spontaneous doubling of the chromosomes obtained a fertile triticale. Until the 1980s, activities in Germany were mainly devoted to cytogenetic and physiological research and also to the production and study of primary triticale. Both hexaploid and octoploid primary triticale was investigated. Breeding research and applied breeding with secondary hexaploid triticale started in the mid-1980s. The genetic material to establish breeding programmes for triticale as a winter cereal crop originated mainly from Canada, France, Mexico and Poland.

Cytological instability, low fertility and shrivelled grain, which were serious defects at the beginning of triticale work, were improved by systematic breeding and are no longer a problem. The current breeding aims are very similar to those of other small-grain cereals: high grain yield, high quality, reduction in plant height, and lodging and disease resistance. Triticale still remains highly susceptible to pre-harvest sprouting. Efforts in breeding and research to improve this complex trait should have high priority in the future.

At the beginning of triticale breeding, inherent good disease resistance from rye was one of the attractive characteristics of the new cereal. With the expansion in growing area, however, the situation is gradually changing. Although triticale can still be regarded as a healthy crop, it is attacked by various diseases. The most important ones in Germany are leaf and glume blotch (*Stagonospora nodorum* only), leaf rust and stripe rust. In some areas, mildew is becoming a major constraint. In the current triticale gene pool, however, there appears to be sufficient genetic variation for resistance to most diseases for successful improvement by systematic breeding (Oettler and Schmid, 2000; Oettler and Wahle, 2001; Schinkel, 2002).

Triticale is treated as a self-pollinated crop, and the pedigree method is applied. The presently 18 registered varieties in Germany are all hexaploid types with the complete A, B and R genomes. They are nearly homozygous and homogeneous lines. The production of hybrid triticale, however, is discussed widely at present.

TABLE 1
Growing area and grain yield of winter triticale in Germany, 1988-2001

Year	Area (*'000 ha*)	Grain yield (*tonnes/ha*)
1988	20	5.0
1989	30	5.4
1990	77	5.0
1991	130	5.5
1992	175	5.1
1993	219	5.3
1994	208	5.4
1995	299	5.7
1996	364	5.8
1997	438	6.0
1998	469	6.0
1999	366	6.1
2000	499	5.6
2001	534	6.4

Research projects investigating various aspects to establish a hybrid breeding programme are under way. These include application of molecular markers to identify and establish gene pools, information on cytoplasmic male sterile (CMS) systems, identification of restorers/nonrestorers and studies on heterosis (Bauer and Renz, 2002; Burger, Oettler and Melchinger, 2002).

The first winter triticale varieties registered in 1986 were of foreign origin. In 1993, two varieties bred in Germany were released. In less than 20 years, triticale has developed into an important cereal crop in German agricultural production. The area under cultivation increased from 20 000 ha in 1988 to an estimated 562 000 ha in 2002, which corresponds to 19 percent of the winter wheat area. During that period, average grain yield increased from 5.0 tonnes/ha in 1988 to 6.4 tonnes/ha in 2001 (Table 1). For comparison, average grain yield in 2001 was 7.9 tonnes/ha for winter wheat and 6.1 tonnes/ha for winter rye. The total production of triticale amounted to 2.8 million tonnes in 2000 and 3.42 million tonnes in 2001. Certified seed of the 18 registered varieties was produced on a total of 14 704 ha in 2001. The areas of the most widely grown varieties were: Modus with 4 653 ha, Lamberto with

2 638 ha, Kitaro with 1 610 ha, Trinidad with 1 588 ha and Trimaran with 1 470 ha (Bundessortenamt, 2002; Statistisches Bundesamt, 2002).

In Germany, as in most European countries, triticale is used as a feed grain for pigs and poultry. Its balance of available amino acids fits the requirements of monogastrics. It has none of the anti-nutritional factors associated with rye (Boros, 1998; Boros, 2002).

Of the total production of triticale, nearly 95 percent is used for feeding, about 3 percent as seed, 2 percent for export and less than 1 percent for alcohol production. The official statistics do not show any use for human consumption. Of the feed grain, about two-thirds is on-farm consumption and one-third goes into commercial feed mixtures. In contrast to wheat, barley and rye, for triticale no quality criteria have been established. Grain yield has been the dominant selection criterion. Triticale and oats are the only cereals not covered by a market intervention system. The average monthly producer price in 2001 was 105 •/tonnes (bread wheat was 116 •/tonnes and bread rye was 108 •/tonnes) (Stratmann, 2002).

Triticale can be grown on a wide range of soils due to its high adaptability. It has a low input and management demand and a high growing cost efficiency. It is attractive, therefore, for intensive livestock-raising farmers with on-farm consumption, as it produces a high-quality feed on low-input systems. On the other hand, triticale is responsive to nitrogen, which makes it also suitable for areas where high amounts of manure are produced. In addition, triticale does well on less fertile soils and in drought-stressed areas. It also has potential in regions were feed barley suffers from winterkill (Banaszak and Marciniak, 2002; Green, 2002).

In Germany, triticale breeding until registration for official trials, maintenance breeding and seed production of released varieties are carried out by private companies. The presently 18 registered varieties come from eight breeding companies. Not all of these companies maintain a complete own-breeding programme. Some of them receive early or advanced generation material from cooperating breeders in other countries, which they test and put into official trials for release.

Breeding research is under the responsibility of public institutions (Plate 1). At present, two institutes are engaged in triticale activities in Germany. These are the Federal Centre for Breeding Research on Cultivated Plants, Gross Luesewitz, and the State Plant Breeding Institute, University of Hohenheim, Stuttgart-Hohenheim. Their research activities include the development of basic genetic material, segregating populations or pre-tested lines that might be interesting for the breeders. All this material is available to them under appropriate agreements.

Besides the aforementioned studies on hybrid triticale, further activities of the institutes include quantitative-genetic studies on pre-harvest sprouting, *Fusarium* and *Stagonospora nodorum* resistance and drought stress. Studies involving both primary and secondary triticale are expected to give information on the most effective use of raw amphiploids in applied breeding.

The basic and applied research of the institutes in Germany is essentially financed by the institutes' budgets. But as a result of funds being cut, they also strongly depend on money from private sources (Landessaatzuchtanstalt, 2000; Federal Centre for Breeding Research on Cultivated Plants, 2001).

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PLATE 1
Triticale breeding plot at the University of Hohenheim, State Plant Breeding Institute, Stuttgart, Germany
G. Oettler

Triticale in Hungary

L. Bona

In the last ten years (1992-2002), winter triticale has achieved outstanding progress in Central Europe. In Hungary, triticale production started in the late 1960s on sandy soil areas in the middle regions of the country, around Kecskemét where Kiss exhibited his pioneer breeding efforts on this crop. After twenty years of inactivity, triticale revival started in the early 1990s. As a result of political changes in 1990, cooperative- and state-owned lands were returned to original owners (or to their descendants), and the renewed small family farms showed a strong interest in triticale. Smallholders and new private farmers quickly discovered the profitability of triticale, particularly on dry, poor, infertile soils. Subsequently, the planting area to winter triticale has been steadily growing (Figure 1), reaching 120 000 ha in 2001.

Spring triticale, a new crop in the area, has received less attention than other crops. In 2000, two Polish-origin spring varieties were registered in Hungary and from that time onwards, farmers' interest has turned to this crop. National Variety Field Tests and recent studies (Bona *et al.*, 2002) indicate that spring triticale has a lower yield potential than winter triticale in the region.

TRITICALE PRODUCTION

The production of triticale is mainly concentrated in the following areas:

- Areas characterized by raw, sandy soils with low pH, low organic matter content and poor in macronutrients. These large areas are located in the northeastern (Nyírség) and western (Somogy) parts of Hungary.
- Areas characterized by sandy soils with a pH of 6 to 9 and low or medium organic matter content. Precipitation is usually very low in these areas (400 to 500 mm/year). These soils are rich in calcium and sodium; sometimes the B horizon is highly sodic. These areas are located in the middle of the country.
- Areas characterized by meadow 'solonetz solods' with dry and compact soils, located in middle of the country.
- Areas characterized by black Chernozem soils and meadows (appropriate for excellent wheat production). To a lesser extent, growers produce triticales on these soils for feed for the pork and poultry industries.
- Areas characterized by red or brown forest soils, located in the western part of Hungary. These are smaller, hilly areas where wheat has poor yield in terms of quantity and end-use quality traits.

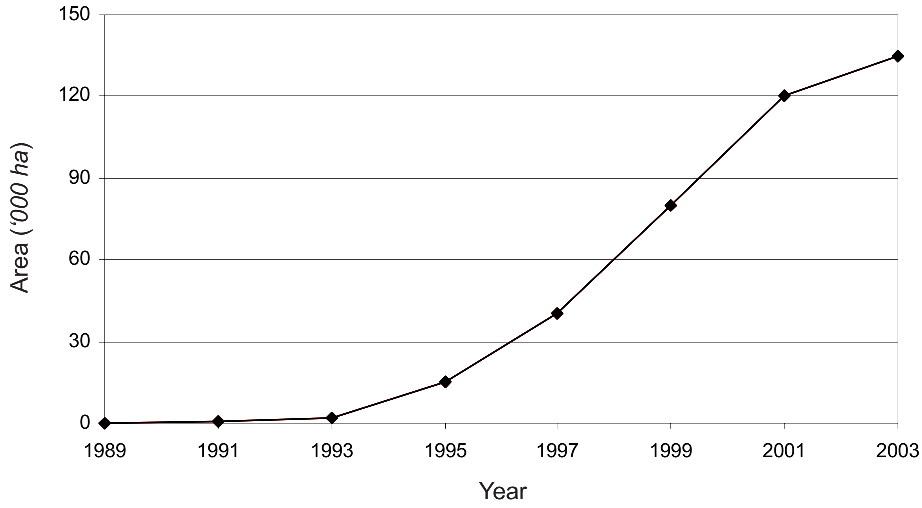
The average grain yield in the poor areas varies between 3 and 4.5 tonnes/ha. However, recent studies revealed that even in the infertile, acidic, sandy soils in northeastern Hungary triticale can produce up to 7.9 tonnes/ha yield, if properly fertilized with nitrogen, phosphorus, potassium, calcium and magnesium (Kádár, Németh and Szemes, 1999). Small-grain variety performance tests have been conducted at National Variety Field Tests proving the excellence of triticale within small-grain cereals. In a five-year period, triticale outyielded wheat and rye except in one year where it had lower yield than wheat.

In summary, on most of the areas where triticale is grown, it has an advantage over wheat in terms of yield stability. Growers appreciate the crop because it can produce satisfactory yield without using fertilizers, pesticides and intensive tillage. Today, on all of the areas previously described, smallholders as well as larger farms utilize this crop as a feed grain for livestock and obtain better results with triticale than with any other crops.

TRITICALE UTILIZATION

Most of the produced triticale grain is used by the growers as a feed grain mainly for pigs and poultry. Triticale has become an important on-farm crop in the last ten years in Hungary. However, farmers have not yet discovered how important triticale can be as an alternative forage crop (mainly as silage) for the cattle industry. One of the weaknesses of triticale is its poor market competition compared to wheat, barley or maize. Triticale has yet to achieve its appropriate market position in Europe (Green, 2002). However, there are several points that will change the present negative image of triticale. Many governments in the European Union aim to change future agriculture policies so that they are more environmentally sound. Also, throughout the world, including Central Europe, there is an extremely strong emphasis on costs and benefits. In terms of unit costs, triticale will be a more favoured crop among farmers in the region. It will be

FIGURE 1
Area planted to triticale in Hungary, 1989-2003



one of the most promising non-food, small-grain cereals for industrial production. Triticale has a prospect as a raw material for bio-fuels (ethanol), organic and industrial chemicals, paper, the building and plastic industries and the beverage (beer) industry. In addition, it may also be possible to utilize triticale as a substitute for wheat and rye for human use in baking and breakfast cereal products (Salmon, Temelli and Spence, 2002; Bona *et al.*, 2002). According Jenkins (personal communication), triticale porridge has a tremendous benefit for the human body, probably due to its high fibre content, essential amino acids and antioxidant activity. Thus, the utilization of triticale in the milling and baking industry will play a more pronounced role in future research.

CROP IMPROVEMENT, VARIETY USE AND SEED PRODUCTION

In Hungary, research on wheat x rye hybrids was started almost 50 years ago by Kiss and Rédei (1952). By the early 1960s, crossing octoploid x hexaploid triticale lines, Kiss had developed the secondary hexaploid populations T-30, T-57 and T-64. He named these populations 'secondary hexaploids' because they originated from crossings of primary hexaploids x octoploids. He released them immediately and started to initiate on-farm trials on sandy soil areas (Kiss, 1966; Kiss and Kiss, 1981). In fact, the Hungarian cultivars T-57 and T-64 were the first triticale cultivars worldwide to be released for commercial production (Zillinsky, 1985). Based on his annually repeated crossings and progeny tests, Kiss (1966) indicated that the hexaploid level should be the optimum genomic level for triticale (rather than the octoploid one). Kiss established modern triticale breeding with his secondary hexaploids, since they were as competitive on marginal soils as rye with 30 to 50 percent more protein.

Despite exceptionally successful breeding work, an adverse political-economic decision blocked the research, development and production of this crop in Hungary. In 1970, the Hungarian Ministry of Agriculture decided to terminate extensive triticale breeding in Hungary, justifying their action by the fact that Hungary was more suitable for wheat production. In 1970, Kiss's dwarf cultivar Bokolo was also patented in Germany, but no interest was shown by the Hungarian authorities. The state officials during that time made international decisions on the scientific and technological cooperation of communist countries. Based on those decisions, Kiss was forced to donate his valuable advanced materials to Polish scientists. From that time onwards, triticale breeding in Poland was enhanced substantially. Polish scientists have made tremendous efforts to improve the adaptation (mainly frost resistance) of triticale (Wolski and Tymieniecka, 1988).

In the last 10 to 15 years, Polish varieties have had significant influence on triticale production all over Europe, including Hungary. During the last decade, only Polish cultivars have been used in Hungarian triticale production areas. Cultivars Presto, Bogo, Marko,

TABLE 1
Main institutions involved in triticale research in Hungary

Institution and location	Main research activities
Agricultural Research Institute of the Hungarian Academy of Sciences, Martonvasar	Adaptation trials; variety introduction; seed production
Agricultural Research Station of the University of Debrecen, Karcag	Breeding; seed production; variety trials
Cereal Research Non-Profit Co., Szeged	Breeding; seed production; quality analysis; adaptation trials; variety introduction

Lamberto and Kitaro are the most popular varieties among Hungarian farmers.

Similarly, in Hungarian breeding programmes, Polish varieties are extensively used to improve adaptation and yield potential of triticale. Nowadays, there are three triticale research programmes in three different parts of Hungary as indicated in Table 1.

These three institutions, where research and development work on triticale is carried out, are public institutions. Breeder and foundation seed are also produced in these institutions. Nevertheless, all certified seed for the country is produced by private companies and farms. The quantity of certified seed sold in Hungary in the last three to four years has been 6 000 to 9 000 tonnes/year. It is expected that 10 000 tonnes/year of certified seed will cover future needs for the country.

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Triticale in Mexico

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Triticale in Mexico has been a disappointment for breeders because almost 40 years of efforts have been devoted to the improvement of this crop without significant impact on its production. Until the mid-1990s, the area planted to this species did not justify the resources that had been invested in triticale research. In 1990, the total area planted to triticale in Mexico was approximately 4 000 ha; however, in 1999, it was estimated that the state of Mexico alone planted more than 4 000 ha using old and new released varieties (Hernández and Macario, 2000). In 2001, more than 2 500 ha in the La Laguna region and southern Chihuahua region were planted to triticale using mainly forage varieties. At present, it is more likely that the area planted to triticale in Mexico is approximately 10 000 ha. The low rate of increase in triticale area before the 1990s could be explained by the lack of implementing an efficient programme of demonstration showing farmers the crop and its advantages. However, during the last five years, large plot demonstrations of triticale have been conducted with farmers in several states. The distribution of bulletins, organization of field days on farmers' plots and the production of seed and its availability have contributed significantly to the expansion of the area grown to triticale in different Mexican states. The potential surface that can be planted to triticale is estimated at 50 000 ha under irrigation and 250 000 ha under rainfed areas (Hinojosa *et al.*, 2002a).

Until recently, triticale was not given any importance by the private sector because it was not a profitable crop. Therefore, all resources required for its diffusion were supplied by the government. Triticale was initially recommended for regions where numerous environmental conditions prevail and where the standard of living is low. In those regions, the most productive crop alternative is triticale because it has been shown that the crop is better than any other grain used in the Mexican diet. In addition, triticale grains constitute an important source of energy due to the high carbohydrate content and good quality of the protein if compared with other cereal grains (Macario, 1998; Carney, 1992). Today, several private companies are promoting triticale, the new forage and grain varieties, mainly in the central and northern states of Mexico. Demand for high-quality seed for large private farms, both dairy and beef production, in these regions has been increasing, offering good opportunities for seed companies (Lozano del Río, 2002).

The grain yields of the first triticale released in Mexico during the mid-1970s exceeded 5.8 tonnes/ha of grain under irrigation conditions, 20 percent less than the wheat varieties. At present, new triticale varieties have the same yield as new wheat varieties (more than 8.0 tonnes/ha). However, under rainfed conditions, triticale yield averages 15 percent more than wheat (Hernández, 2001). Under good rainfed conditions (700 mm/year), triticale has produced 6.5 tonnes/ha, while under low rainfed conditions (300 mm/year), triticale yields 2.5 tonnes/ha (Hernández and Rodríguez, 1998; González Iñiguez, 1991). As forage, triticale also yields more than wheat, barley and oats. Under very low rainfed conditions (196 mm/year), spring-type triticales produce significantly higher forage yields than the traditional oat cultivar Cuauhtemoc (5.3 to 7.4 tonnes/ha versus 3.4 tonnes/ha, respectively). Triticale has considerable regrowth after cutting at full-flowering stage, whereas little or no regrowth was observed in oat (Hinojosa *et al.*, 2002a). Under irrigation, diverse studies in northern Mexico showed that facultative and winter-intermediate triticales have higher dry-matter yields than other winter forage crops (oats, wheat, barley, rye and annual ryegrass). Overall, dry-matter yield of triticale ranged between 8.5 and 25.0 tonnes/ha depending on the growth habit types: spring, intermediate or winter types. In general, winter and intermediate triticales outyield spring types in forage production by approximately 30 percent. Furthermore, they provide better distribution of production across different cuttings (Lozano, 1991; Lozano *et al.*, 1998; Mergoum *et al.*, 1999). During the 1997-2001 period, a number of facultative and winter triticale lines were compared with traditional forage crops, such as oats, ryegrass, barley, wheat and rye, under various agro-ecological conditions. The results demonstrated the advantage of triticale over all these forage crops, both in terms of forage productivity and forage quality parameters. These results, combined with the ability of triticale to perform well under marginal soil conditions, such as drought stress and low temperatures, have contributed to the increase in adoption of triticale by a number of farmers in the northern region of Mexico (Lozano, 1991; Lozano *et al.*, 1998; Mergoum *et al.*, 1999; Hinojosa *et al.*, 2002b).

TRITICALE PRODUCTION

Triticale is grown under a wide range of soil and climatic conditions, including dryland and marginal soils. Under high input and rainfall environments, the best triticales and wheats have comparable grain yield, with a slight advantage for the triticales. This advantage is much larger under dry and marginal conditions. Comparisons made with bread and durum wheat indicated that the modern spring-habit triticale genotypes yield as good as or better than the best yielding bread and durum wheats when lodging is avoided. Also, data have shown consistently the yield advantage of complete triticales compared to substituted genotypes (Sayre *et al.*, 1998). Hence, triticale is in general a sustainable crop for harsh and marginal farming systems (Estrada *et al.*, 1998). Triticale yields more than its ancestors in two types of marginal conditions: (i) highlands where acid soils, phosphorus deficiency and foliar diseases are dominant; and (ii) in the arid and semi-arid zones where drought affects crop production (Carney, 1992). In these environments, triticale can be a good substitute where maize has difficulties producing due to poor soils and a lack of rain. Under these conditions, triticale has shown many advantages over maize, wheat, barley and beans (Hernández, 2001). These environments are also the ones where social and economic problems play an important role as a result of poverty, illiteracy and malnutrition. In these specific regions, triticale could be the ideal crop, not only for its tolerance to the poor environmental conditions, but also for its high protein quality and the good flavour it provides to triticale tortillas when mixed with maize.

In the plateau of the central states of Mexico, triticale is produced under rainfed conditions. However, some farmers grow triticale during the winter, providing some irrigation or using soil residual moisture from previous rains (Hernández and Rodríguez, 1998). In the state of Michoacán, cereal-growing area altitude varies between 2 000 and 2 500 masl. In these environments, farmers grow dispersed fields in volcanic hills, valleys and special areas (Carney, 1992). The soils are predominantly deep, acid Andisols characterized by low fertility, low organic matter content (less than 3 percent) and high moisture retention capacity. The rainfall patterns in the central highlands of Mexico are highly variable. This is reflected in the grain yields of small cereals grown in this region. These yields ranged from 1 to 6 tonnes/ha across different years. Moisture stress can last from pre-anthesis to post-anthesis (González Iñiguez, Castrejon and Venegas Gonzalez, 1996). Traditionally, triticale in these environments has been planted with a seeder or by dispersing the seed with a machine or by hand. The crop is also planted in rows similar to maize. In these regions where rain is scarce and erratic, the best system to produce triticale is in rows allowing the rain that falls to run to the low part of the row where the seed is placed, improving soil moisture for better germination and development of the plants. Smallholder farmers across the country grow triticale for its comparative advantages, including higher production, better animal nutrition and its impact on animal sub-products, such as milk and eggs. In addition, triticale straw is highly appreciated as feed for cattle and often mixed with maize stubble. Other farmers grow triticale for grain used for dairy cows, poultry and swine. Triticale was shown to constitute an excellent feed for animals because it increases daily milk production (Carney, 1992).

Under the low rainfed conditions of the arid and semi-arid regions dominating the northern regions of Mexico, triticale is resistant to most diseases, and it has a low water demand compared to other currently cultivated crops, such as maize. Therefore, triticale has substantial comparative advantages as an alternative crop for winter forage production in northern Mexico. The northern region constitutes the largest semi-arid zone of Mexico and has a large diversity of climates and soil characteristics. Alkaline soils and extreme winter temperatures with relatively low (200 to 400 mm annually) and erratically distributed rainfall during summer (May to September) are dominant in this region. The region is very important for livestock production, mainly beef and dairy cattle (Plate 1) (Lozano, 1991).

Triticale is a robust crop with high forage and grain yield potential, good nutritional quality and frost tolerance. It is a very promising alternative forage for the irrigated regions of the northern and central states of Mexico including Durango, Coahuila, Nuevo León, Sonora, Zacatecas, Aguascalientes and Chihuahua. The La Laguna region is the most important area for milk production in Mexico, whereas in Chihuahua beef and dairy cattle are dominant (Hinojosa *et al.*, 2002a). In addition, the northwestern part of Chihuahua, a large rainfed area with a yearly rainfall between 400 and 600 mm, grows more than 200 000 ha of oats (80 percent of the total area of oats in Mexico) (Hinojosa *et al.*, 2002a). In this region, frost between September and March (10 to 60 days), with minimum temperatures as low as -18°C, can damage substantially the oat crop, which is a frost-sensitive crop compared to winter triticale. In recent years, severe droughts combined with frost as early as September have forced farmers to reduce the area planted to oat and look for new alternatives (Hinojosa *et al.*, 2002a; Lozano, 1991).

Other crop production systems involving triticale include the association of triticale with barley, oats, vetch and berseem clover in mixtures for forage use and intercropping triticale with maize, beans and chickpea. The use of mixtures of facultative or intermediate triticales with annual ryegrass during winter maximizes forage production and quality under irrigated conditions in the northern and central regions of Mexico. Facultative triticale-ryegrass mixtures surpassed, in general, their monocultures in dry-matter production (Lozano del Río *et al.*, 2002a). The most important aspect of this mixture is the relative stability of production, particularly for grazing conditions. This is a very important factor for pastures because it allows a higher and more uniform dry-matter production for longer periods (Lozano, 1991).

The main constraints for triticale production in humid regions are diseases, such as scab caused by *Fusarium* sp., bacteriosis caused by *Xanthomonas* sp., leaf spot and blights caused by *Helminthosporium* and stripe rust caused by *Puccinia striiformis*. In semi-arid regions with late heat during the growth period, as is the case in northern Coahuila, Nuevo León and Tamaulipas, however, the main disease is leaf rust caused by *Puccinia triticina* (González Iñiguez, 1991; González Iñiguez *et al.*, 1996). Under high rainfed conditions, most triticale cultivars are susceptible to sprouting causing grains to germinate in the spikes. However, there are some new varieties that have some kind of tolerance to this problem.

TRITICALE USES

In Mexico, 90 percent of the triticale production is utilized for animal feeding. With the release of a new generation of varieties, however, farmers and processors are renewing interest in producing this crop for other uses. Triticale is seen as the solution for agricultural production in areas where rain and temperatures are the main obstacles for food production (Pat and Hernández, 2001). Triticale grain is rich in some essential amino acids needed by humans. Its grain is also an important source of protein and energy that can be utilized in animal feeding and for human consumption in regions where protein sources in human diets are very scarce or too expensive to access by poor people. This is particularly true for sources of amino acids included in meat or milk proteins needed in children's diets for better mental growth and development (Hernández and Macario, 2000; Carney, 1992).

Triticale grain is also suitable for making of all kinds of pastries, such as doughnuts, cookies, hot cakes and tortillas. In the central Mexican states, triticale is utilized for manufacturing tortillas made with 90 percent maize and 10 percent triticale. These kinds of tortillas are sweeter than when using wheat in the same proportion with maize due to the high percentage of sugar contained in triticale. Triticale grain is also used to make all kinds of breads when mixed with wheat grain, and germinated triticale grains can be a good energy source in human or animal diets. Currently, triticale grain blended with other grains is used as feed at the commercial level (Hernández *et al.*, 2001).

The northern region of Mexico, which includes the states of Coahuila, Durango, Chihuahua, Sonora and La Laguna, is very important for livestock production, mainly beef and dairy cattle. Irrigated pasture crops are widespread and used for grazing, hay or silage. In La Laguna, the most important dairy area in Mexico, the most common use of triticale is for hay or silage, while in other areas, especially Chihuahua and central-north Coahuila, grazing is more common. Until today, the traditional winter forages have been oats and ryegrass. Farmers in these regions have rapidly accepted triticale as a forage crop, basically due to its high biomass production but also because of its cold tolerance. Low temperatures often damage or restrict the growth of oat and ryegrass but do not harm triticale (Lozano, 1991; Hinojosa *et al.*, 2002b).

Results from experiments in which triticale was evaluated for dry-matter production and nutritional value demonstrated that winter/facultative triticales significantly outperformed traditional forage crops, such as oats and ryegrass (Lozano *et al.*, 1998). Experiences from the La Laguna region have shown that triticale is far more water-use efficient than oats, wheat and ryegrass, an important factor in regions where irrigation is a major constraint for forage production. After evaluating many triticale lines, several superior triticales have been identified for northern Mexico and will be released during the 2002/03 crop season.

High biological value forage is essential for the northern states of Mexico where cattle production is very important. The scarcity of water and low temperatures in winter oblige farmers to grow input-efficient crops with profitable forage production levels to provide the forage supply needed during the winter period. In general, early- and late-winter growth habit triticales significantly outperformed the controls, ryegrass and oat, in green forage and dry-matter forage yields. Nutritional value analysis revealed high levels of protein content (PC) and adequate contents of acid detergent fibre (ADF), neutral detergent fibre (NDF), total digestible nutrients (TDN) and energy for triticale. The high forage biomass production and forage quality of triticale increase animal performance, reduce feeding costs and result in increased returns for the farmers (Lozano *et al.*, 1998). Moreover, environmentalists report that the straw of triticale, packed very well, may be used instead of bricks in the construction of houses and buildings. Triticale straw can also be a source of raw material to make hard paper or to use as bedding for cattle. It can be incorporated into the soil as organic matter to improve poor soils, and the straw can be used in the production of all kinds of mushrooms (Hernández, 2001).

TRITICALE IMPROVEMENT

The introduction and genetic improvement of triticale started in Mexico with an international research programme in 1964 (Zillinsky, 1973). Ten years later, the first two varieties, Bacum and Yoreme, were released. These varieties were well adapted to some regions in the states of Hidalgo, Jalisco, Michoacán, Zacatecas, Chihuahua, Oaxaca, Chiapas and Coahuila (Hernández, 2001). In 1974, many plots of 1 ha were planted in those states to show the farmers how the two triticale varieties performed under local conditions. Farmers were interested in triticale because it was more vigorous and had longer spikes than wheat. Despite the fact that triticale had low grain yield, low test weight, shrivelled grain, lodging and late maturity, farmers were still interested because they saw that it performed far better than wheat in poor environments.

In the 1970s, a farmer in the state of Michoacán noticed that feeding dairy cows with triticale grains increased the production of milk. The farmer maintained producing triticale. In 1978, in the small town of Erongaricuaro in Michoacán, production of triticale on more than 50 ha was used to make whole-grain bread in some bakeries. That town became famous for its bread made with triticale (Carney, 1992; Hernández, 2001).

Since 1974, many cultivars have been developed by the International Maize and Wheat Improvement Center (CIMMYT), which is one of the 16 organizations constituting the Consultative Group for International Agricultural Research (CGIAR). These cultivars have been evaluated and released by Mexican research programmes (Instituto de Investigación y Capacitación Agropecuaria, Acuícola y Forestal del Estado de México [ICAMEX], Instituto Nacional de Investiaciones Forestales, Agrícolas y Pecuarias [INIFAP], Universidad Autónoma Agraria Antonio Narro [UAAAN] and Universidad Autónoma del Estado de México [UAEM]) to be cultivated in different regions of the country. The triticale cultivars that have had more impact on production are: Navojoa, Eronga, Huamantla, Jilotepec, Secano, AN-31 and AN-34. These last two varieties are forage-type, winter or intermediate genotypes utilized mainly for multiple cuts for hay, silage or grazing (Lozano del Río *et al.*, 2002b; Lozano del Río *et al.*, 2002c). More recent varieties released for grain production are Milenio-TCL3 (Mergoum *et al.*, 2001a), Siglo-TCL21 (Mergoum *et al.*, 2001b) and Supremo-TCL2000 (Hernández *et al.*, 2001). These recently released triticale cultivars have improved grain yield and plumpness, resistance to lodging and shattering, a shorter cycle to maturity, higher fertility and test weight and reduced plant height. The variety Siglo-21 has been cultivated widely, allowing its seed to be multiplied faster and in large quantities to supply farmers' demand. More than 1 000 tonnes of seed have been sold in the state of Mexico to plant more than 6 500 ha. Seed in the state of Mexico is produced by the state research institute (ICAMEX) and by several small farmers. Some of these farmers commercialize their seed through the government programme Kilo por kilo (see chapter "Triticale marketing: strategies for matching crop capabilities to user needs"); other seed producers have their own market, and they sell seed to their neighbours (Hernández, 2001). The seed produced by ICAMEX in the state of Mexico is commercialized through the government programme Kilo por kilo and sold to some farmers from other states, such as Jalisco, Puebla, Tlaxcala and Guanajuato. The Universidad Autónoma Agraria Antonio Narro (UAAAN) in Coahuila in northern Mexico has released most of the triticale utilized as forage. The seed of these forage-type varieties is sold by private enterprises in the northern and central states of Mexico (Lozano del Río, 2002).

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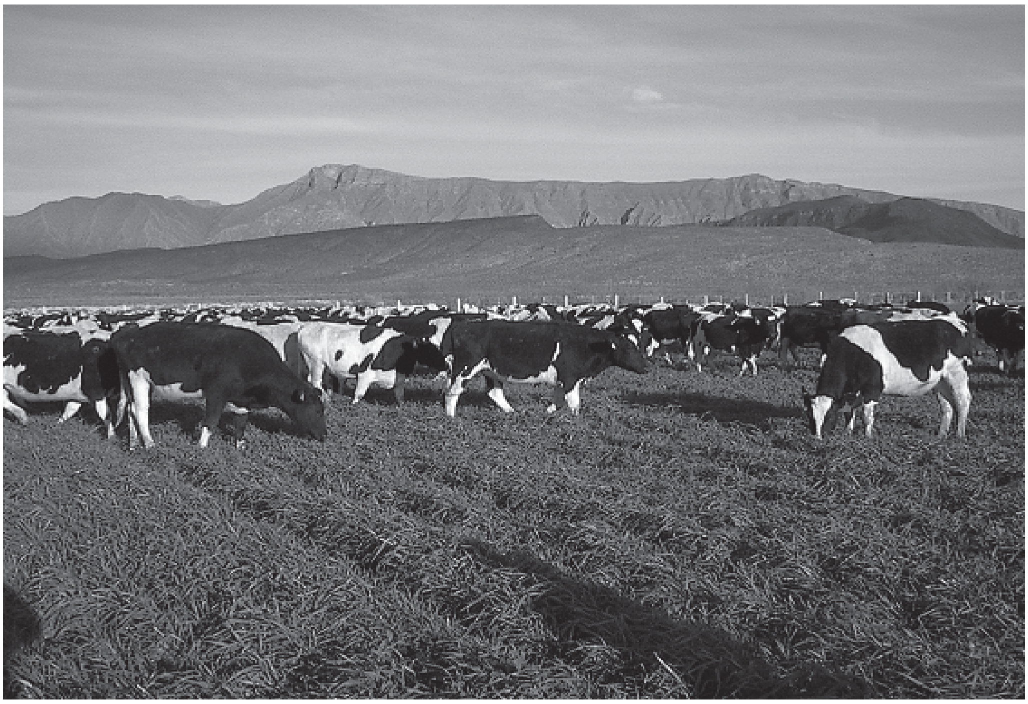
PLATE 1
Holstein heifers grazing AN-31, an intermediate-winter triticale, at Cuatrocienegas, Coahuila, Mexico
A.J. Lozano del Río



Triticale in Poland

E. Arseniuk, T. Oleksiak

Research and breeding of triticale in Poland was started in the 1960s, i.e. a few years after work was undertaken in Europe and America (Shebeski, 1980; Tarkowski, 1989). The first Polish cultivar Lasko was registered in 1982 and Dagro in 1984. At that early stage, triticale research and breeding was focussed on winter types. In the 1980s, triticale in Poland developed rapidly. The crop was enthusiastically and widely accepted by farmers, and its sowing area increased each year considerably. In the 1990s, the area planted to triticale in Poland stabilized and even dropped slightly (Smagacz, 1999). The main reason for this was the limited production of triticale by state-owned farms. In the late 1990s, 600 000 ha of triticale was grown in Poland. In recent years, farmers have shown a new interest in winter triticale growing, and triticale area under commercial production increased to 734 000 ha in 2001. Winter triticale is grown mainly in the following regions: Wielkopolska, Ziemia Lubuska, Gdañsk, Pomerania, Warmia, Mazury and central Poland. In addition, triticale is grown quite extensively in the former voivodships of Czêstochowa, Skierniewice and Bia³a Podlaska (Figure 1).

The breeding successes of winter triticale have contributed to a greater interest in spring triticale. The outcome of breeding work on spring triticale was the registration of spring cultivars Jago in 1987 and Maja in 1988. However, it should be noted that originally spring triticale generated less enthusiasm than winter triticale. Nonetheless, the slow increase of spring triticale growing area resulted in 106 000 ha in 2001. Spring triticale is grown in northern, western (3.3 percent in the Zielona Góra region) and central (3.5 percent in the Mazovian voivodship) Poland and in Silesia (Figure 2). The economic importance of spring triticale is not high. It is used mainly for animal feeding. At present, five spring triticale cultivars are on the official list of varieties. They differ from each other in yield potential and agronomic characteristics. In general, yield potential and resistance to diseases, lodging and sprouting have been decisive as to whether or not a triticale cultivar can be commercially produced.

Triticale holds a strong position in Polish plant breeding (Czembor, 1999). In total, 41 winter-habit triticale cultivars and seven spring-habit triticale cultivars have been released so far. Currently, 28 cultivars of winter habit and five cultivars of spring habit are on the official list of varieties. In addition, six winter cultivars designed for export are included in the register. It should be underlined that according to data from the Organisation for Economic Co-operation and Development (OECD) 19 triticale cultivars from Poland have been placed in the variety catalogues of 13 countries (OECD, 2001). Winter triticale cultivar Presto is registered in six countries, and winter cultivar Ugo registered under the name Modus has been grown extensively in Germany. Other well-known winter triticale cultivars with high yield potential are Tornado, Kitaro, Kazo (2000) and frost-resistant cultivar Janko (2000). Among cultivars registered in 2001, Hewo, Krakowiak and Sekundo are especially suitable for growing in southeastern Poland. The breeding of cultivars with short straw and high resistance to lodging has been successful. Bogo was the first such cultivar registered in 1993, followed by short-straw cultivars Fidelio and Woltario. Winter triticale cultivar Fidelio provided one-third of the certified seed production in Poland and is used as a reference cultivar in the United Kingdom of Great Britain and Northern Ireland. In 2002, three new winter triticale cultivars were released: Pawo and Witon (released by breeders from Malyszyn Experiment Station) and Sorento (released by breeders from Danko Plant Breeding Co.) (Wolski, 1995; Wolski *et al.*, 1998).

Apart from advantages, which have made triticale competitive with rye and wheat, there are also triticale disadvantages, such as sensitivity to grain sprouting or long growth period. Higher yielding is associated with lower protein content in grain. Spring triticale breeding was the responsibility of the Plant Breeding and Acclimatization Institute (IHAR) in Radzikow. After 2000, breeding was taken over by Strzelce Plant Breeding Company Ltd., established on the basis of former IHAR Experimental Stations.

Triticale cultivars released in Poland have wide adaptation and could be grown in all geographical regions of the country. Leaf rust (*Puccinia triticina*) and sporadically stripe rust and stem rust, Stagonospora

FIGURE 1
Geographical distribution of winter triticale production in Poland; percentage as compared to total cereal-sowing area

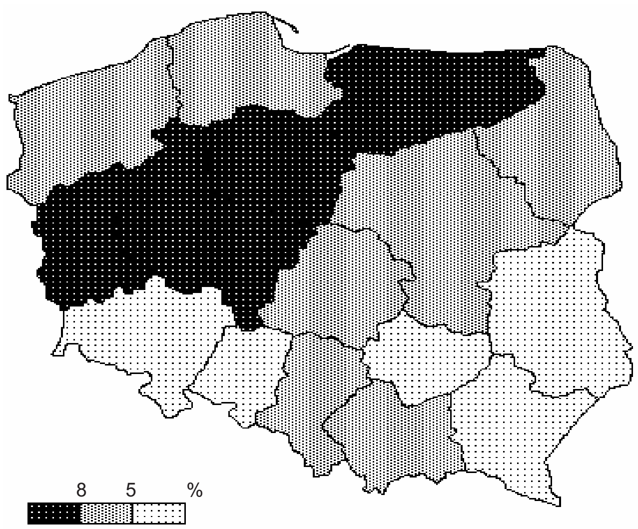
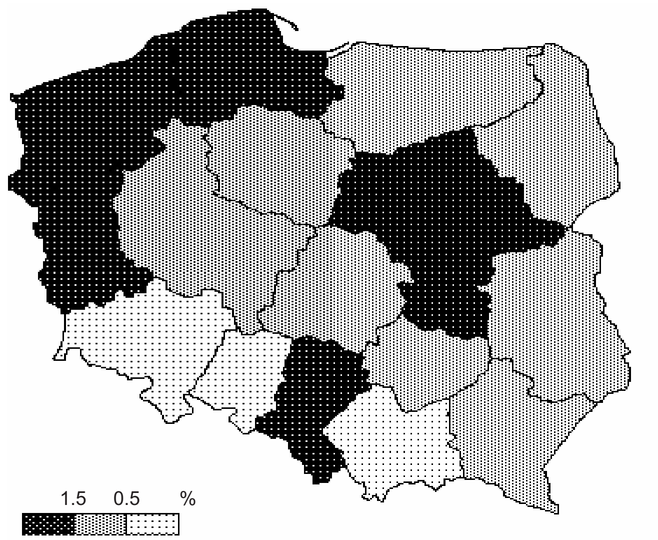


FIGURE 2
Geographical distribution of spring triticale production in Poland; percentage as compared to total cereal-sowing area



nodorum blotch, scab, Rhynchosporium scald, take-all (*Gaeumannomyces graminis*), foot and root rots caused by *Microdochium nivale* and *Fusarium* sp. and eyespot (*Pseudocercosporella herpotrichoides*) are the main diseases that afflict triticale in Poland (Arseniuk, 1996; Arseniuk *et al.*, 1999).

Changes in the yield of winter triticale under experimental and production conditions in relation to winter wheat and rye are shown in Figure 3. The yield of winter triticale in experimental field tests increased over several years with an average yield over 7 tonnes/ha. Triticale appears to be the highest yielding cereal species in Poland.

The grain yields of cereals under commercial production conditions over the last decade have not changed substantially. A lack of yield increase was caused

FIGURE 3
Wheat, triticale and rye yields under commercial production and trial conditions; numbers above bars and lines are relative percentages to wheat yield

Source: Krzymuski and Oleksiak, 1997.

by factors related to cultivation technology, which was influenced by an agricultural and economic recession in Poland. This explains why the difference in cereal yields between experimental and production conditions increased. Additionally, an increasing area of wheat grown each year pushes triticale and rye to be grown in poor and marginal soils. Other factors affecting cereal yield are mineral fertilization, use of chemicals to control pests and diseases and use of new cultivars and certified seed for planting.

Finally, it should be pointed out that average triticale yields in commercial production during the 1999-2001 period represented only 43.8 percent of yields obtained in experimental trials. This relationship was much better than in rye and much less than in wheat. The problem is that the new cultivars developed by breeding companies are not directly associated with certified seed production (Oleksiak, 2000), which delays the introduction of modern cultivars into commercial production. Low demand for certified seed is a common phenomenon. In the case of triticale, however, reduction of demand for certified seed is relatively unimportant. In 2001, the area grown to triticale in Poland increased substantially. Despite this increase, the certified triticale seed used for planting constituted only 12.3 percent. It is obvious that such a low use of certified seed resulted in a slower introduction of new cultivars into production, which undermines any progress made in plant breeding. It is worth mentioning that in large farms the use of certified triticale seed was significantly higher (Table 1). The increase in average triticale area observed in recent years is certainly encouraging. Such an increase in crop production was also accompanied by higher production inputs, such as certified seed, fertilizers and pesticides. In large production areas, the use of mineral fertilization and chemical crop protection were almost doubled compared to other areas. Triticale production using higher inputs appeared to be associated with higher grain yields that compensate the production costs (Table 1).

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TABLE 1
Relationship between triticale plantation size and the use of production means[a]

Production means	Area of triticale field				
	<0.5 ha	0.5-1.0 ha	1.0-2.0 ha	2.0-5.0 ha	>5.0 ha
N (*kg/ha*)	43.3	53.1	58.3	68.0	81.7
P_2O_5 (*kg/ha*)	25.0	27.0	32.4	40.2	41.6
K_2O (*kg/ha*)	21.7	28.0	34.5	44.9	52.1
NPK (*kg/ha*)	90.0	108.1	125.2	153.1	175.4
Herbicides	0.66	0.79	0.84	0.98	1.00
Fungicides	0.17	0.13	0.13	0.26	0.45
Certified seed (%)	31.4	27.5	31.4	35.2	51.0
Cultivar value[b] (*kg/ha*)	-110	-150	-140	-20	80
Sowing rate (*kg/ha*)	236.3	232.7	242.5	232.7	230.0
Age of a cultivar since release (*year*)	8.3	8.8	8.6	7.5	6.9
Soil quality (*points 0-100*)	49.6	52.7	48.7	47.0	44.8
Relative yield (%)	92.3	93.9	94.6	105.8	111.2
Yield (*kg/ha*)	3 410	3 510	3 540	3 970	4 210
Number of fields	137	345	444	318	98

[a]Average values of survey data for the period 1995-2000.
[b]Yield deviation from a standard.

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Triticale in Portugal

B. Maçãs

Farmers in Portugal first cultivated triticale in 1979. By the end of the 1980s, Portuguese farmers were growing an estimated area of 80 000 ha. Triticale was mostly grown for grain and used mainly for feeding. After 1992, with the new Common Agricultural Policy (CAP) reform, the area grown to triticale started to decrease due to a shift in subsidies allocated to wheat. In the 2000/01 crop season, 32 425 ha were grown to triticale and half of this area was used for forage purposes.

The main cereal-growing region in Portugal is located in the southern part of the country, which has a strong Mediterranean climate. Both climate and soil conditions are variable. Despite the good amount of rainfall, its distribution remains the main limiting factor for cereal yields. Other constraints, such as low-fertility soils, toxicity caused by Al^{+++} and Mn^{++} in acidic soils, late frosts that occur during anthesis and heat stress during grainfilling, also limit cereal production in these regions.

Planting starts after the first rains in autumn and continues until 15 December. Spring and facultative triticale types are both grown in the region. True winter types cannot be used due to vernalization requirements.

Although production of triticale on the farm scale started in the 1980s, research involving triticale in Portugal began much earlier. Victória-Pires, the founder of the National Plant Breeding Station at Elvas, pointed out in 1937, in his general guide for the establishment of a breeding programme for cereals and forages, the interest of exploiting the progenies of crosses involving the genera *Triticum* and *Secale* in order to obtain a plant with adaptation to low-fertility soils (Victória-Pires, 1939). This first work on triticale resulted in an octoploid line S. José derived from a cross between bread wheat Ardito and the rye Petkus (Villax, Mota and Ponce-Dentinho, 1954). S. José showed very poor agronomic characteristics but was successfully used in cytogenetic studies to achieve good scientific information.

In 1967, the triticale programme at Elvas received the first triticale nursery from the International Maize and Wheat Improvement Center (CIMMYT). At the beginning, all the genotypes were very poor, showing low spike fertility, tall straw, shrivelled kernels and very low yields. But the rapid progress achieved by the CIMMYT triticale programme allowed the release of one Armadillo line, which was the first triticale actually grown in Portugal (Barradas, 1982). Following Armadillo, a second generation of varieties showing interesting characteristics was distributed to farmers. The most successful varieties were Arabian and Bacum substituted cultivars derived from the M2A line, with 2D/2R substitution, and Beagle, a complete triticale (Table 1). These varieties showed excellent results and stimulated triticale cultivation in Portugal (Bagulho *et al.*, 1996). At that time, the substitution-type varieties were extensively used by farmers due to their better threshing ability. However, the kernels were shrivelled showing low test weight. At Elvas, the breeding programme during the 1980s focussed on improving kernel characteristics, selecting for better tillering in order to increase the number of grains/m^2 and selecting for long-cycle germplasm. This effort resulted in the release of the variety Alter, selected in the Rhino'S' cross from CIMMYT (Table 1).

The data in Table 1 show the progress in yield potential is mainly due to increasing kernel number and 1 000 kernel weight. Harvest index still tends to be low (26 percent compared with 30 percent for durum wheat for the same period of trials), but steady improvements have been recorded, indicating that work should continue with this trait (Maçãs, Coutinho and Bagulho, 1998).

In summary, marked progress has been achieved with spring triticale varieties, with special reference to yield potential, improved test weight and yield stability, but growth cycle is still not suitable for winter grazing.

After the CAP reform in 1992, the traditional use of triticale decreased, and farmers started to demand varieties suitable for grazing and silage. Therefore, an intensive crossing programme was started at Elvas to promote the introgression of winter genes onto spring genotypes. Although CIMMYT material is still the most important source of germplasm both for field evaluation and as parental material, winter and facultative genotypes are being used extensively to enhance the diversity of the germplasm base in order to select genotypes with a longer growth cycle.

In order to maintain the intergenomic genetic balance within triticale genotypes, the crossing programme

TABLE 1

Range and mean values for grain yield, yield components, test weight and days to heading for Alter and older triticale varieties released in Portugal[a]

Variety	Grain yield (*kg/ha*)	Number of kernels/m^2	'000 kernel weight (*g*)	Test weight (*kg/hl*)	Days to heading[b] (*days*)
Arabian	2 570-7 027	7 637-14 397	33.65-49.74	65.32-72.15	19-31
	4 296	-	42.15	68.60	25
Bacum	2 784-7 308	8 926-14 222	31.19-52.91	65.68-75.45	16-32
	4 686	11 088	41.86	69.32	26
Beagle	3 309-6 539	8 768-14 169	34.59-52.45	64.15-68.75	25-32
	4 435	10 218	43.14	66.58	29
Alter	3 473-10 092	9 227-20 504	35.20-59.01	70.55-79.00	22-36
	5 890	13 007	44.49	75.32	30

[a]Data are average over eight year trials at Elvas, Portugal.
[b]Days to heading after 1 March.

TABLE 2

Forage yield and quality means for winter cutting and grain yield, straw and harvest index for regrowth of three different growth-habit triticale germplasms[a]

Growth habit	Winter cutting[b]			Regrowth[b]			
	Biomass (*kg/ha DM*)	Protein (*% DM*)	Fibre (*% DM*)	Biomass (*kg/ha DM*)	Grain yield (*kg/ha*)	Straw (*kg/ha*)	Harvest index (*%*)
Early triticale	4 737	17.05	20.53	12 581	3 787	8 794	30
Facultative triticale	4 311	17.91	20.82	14 761	4 198	10 563	28
Winter triticale	3 678	18.18	20.01	15 718	3 854	11 864	24

[a]Tested at Elvas, Portugal, over three years.
[b]DM = dry matter.

includes different types of crosses: three-way crosses among triticales where the first cross is spring x winter or facultative and the third parent is facultative; triticale x bread wheat x triticale; and triticale x durum wheat x triticale. The main goal is to transfer valuable traits, such as low vernalization requirement, day-length sensitivity, late flowering, short grainfilling period, high tillering and early growth for grazing in winter as well as good recovery after grazing.

The first variety released nationally with these characteristics was Fronteira, which has some vernalization requirement and hence can be classified with the facultative types. The timing of availability of green forage in winter is very important for feeding animals in the field. In southern Portugal, animals (cattle, sheep and pigs) are left free to graze all year long. With this system, there are two critical periods for livestock feeding, winter and summer (Maçãs, Coutinho and Dias, 1998). In winter, forage legumes and grasses, such as ryegrass, have problems due to their lack of resistance to frost. During summer, drought and high temperatures do not allow growing any crop. Thus, intensive work has been carried out to identify germplasm suitable for these systems. The production of winter forage with good regrowth capacity is influenced by the growth habit of triticale, as shown in Table 2.

Facultative triticale types showed better performance when combining early growth with good recovery capacity after grazing. The growing point of these materials was not destroyed by the animals, assuring good regrowth after grazing. Almost all advanced genotypes were submitted to animal grazing or cut during the selection process in order to have materials that could accumulate high dry matter during winter while keeping the growing point below or at the soil level.

In Portugal, public institutions conduct all triticale breeding work. The National Plant Breeding Station at Elvas has been conducting the main programme. This programme released seven of the ten varieties that are included on the national list of released varieties. A second research programme is located at the University of Trás-os-Montes e Alto Douro in Vila Real. This programme recently released one variety under the name Douro, a variety very well adapted to the conditions in the northern part of the country.

In the future, triticale has a major role to play in

Portuguese agriculture, mainly as forage but also as a grain source. The advantages of triticale can overcome some of the difficulties imposed by the CAP policy of the European Union. In rainfed systems, there is unfortunately no viable alternative for cereals, therefore, triticale appears to be a very good crop to include in rotations with wheat. It may provide the solution to take-all (*Gaeumannomyces graminis*) diseases in wheat. In the 2001/02 crop season, in adjacent trials conducted at Elvas in a field with a very strong attack of take-all, triticale produced almost double that of bread wheat. In addition to this advantage, triticale is also efficient in using nutrients, which maybe promising for organic systems which are increasing in Portugal.

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Triticale in Spain

C. Royo, D. Villegas, L.F. García del Moral

The area devoted to triticale in Spain increased sharply between 1986 and 1989 when it reached 75 500 ha (Figure 1). From 1989 onwards, triticale cultivation declined due to its replacement by other subsidized field crops, mainly durum wheat. At present, triticale covers about 32 000 ha with a total production of 75 000 tonnes, averaging 2.3 tonnes/ha (Figure 2). The export market is minor, while within the country the average price received by farmers for this grain has decreased 16 percent since 1995 to 130 •/tonne in 2000 (Figure 3).

TRITICALE CULTIVATION

In Spain, triticale is generally cultivated under rainfed conditions, mostly in the southern regions of the country: Andalusia (which accounts for about 65 percent of the area) and Extremadura (with about 20 percent). These regions have a Mediterranean climate, with an average annual precipitation of about 450 mm, usually distributed evenly throughout the growing season. Terminal drought stress is the main abiotic constraint to the crop. However, minor cultivation areas are scattered in central-eastern regions (Castilla-La Mancha, 11 percent), the Balearic Islands (3 percent) and northeastern zones (Catalonia, 1 percent). The central and northern regions have a more continental climate, with lower temperatures during winter and spring and very high temperatures and water stress during grainfilling. Rainfall is lower (200 to 300 mm) and less evenly distributed. Hail damage (Plate 1) may occur occasionally. In the wet northern region, grain damage due to sprouting (Plate 2) may occur. Biotic stresses have not limited the cultivation of triticale in the past. However, some varieties have recently become susceptible to foliar diseases, especially leaf rust.

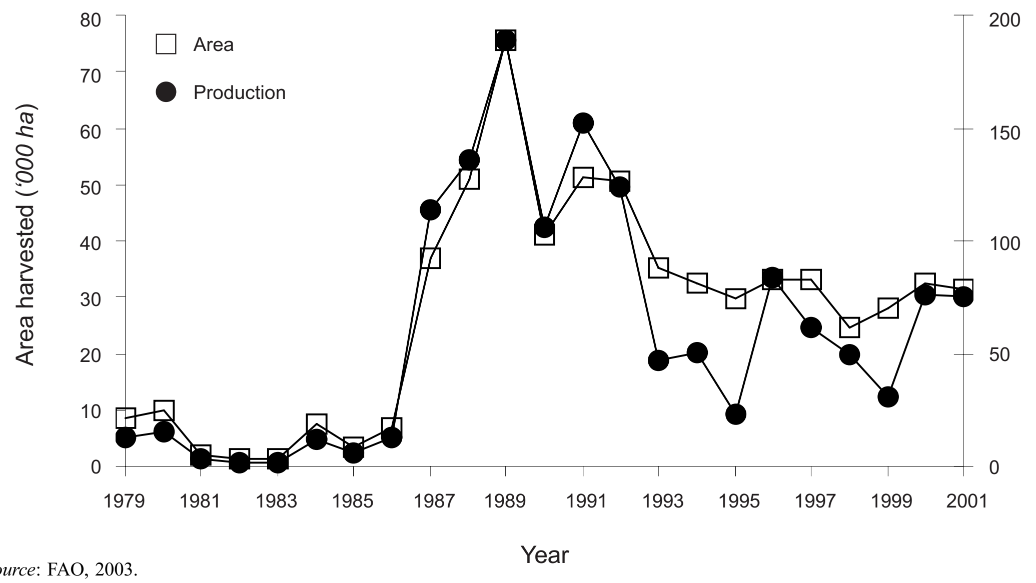
Most of the triticale varieties cultivated in Spain are spring types that admit an alternative sowing, even during autumn. Planting is generally carried out in November. Earlier sowings are not recommended in cool areas to avoid frost damage (Plate 3) to the crop during spring or aphid infestations during autumn (Royo, 1992). The impact of a delayed sowing date and drought on grain growth and morphometry has recently been investigated (Royo *et al.*, 2000). Recommended sowing densities range between 200 and 250 kg/ha. One of the advantages of triticale compared with barley or wheat is its early vigour, which enables a fast crop growth during the first stages of development and a rapid cover of the soil by the crop canopy. Moreover, during its vegetative growth, triticale is much less attractive to rabbits and other rodents than other small-grain cereals.

END-USES

Triticale was first introduced in Spain as a grain crop. Under the Mediterranean conditions of Spain, triticale grain can provide between 300 kg/ha of crude protein under rainfed conditions to almost 900 kg/ha under irrigation, with a content in essential amino acids (g aa/100 g protein) ranging between: 1.98 and 2.29 for lysine; 0.94 and 2.04 for methionine; 3.02 and 3.44 for phenylalanine; 4.25 and 4.52 for threonine; and 4.83 and 4.98 for leucine (García del Moral *et al.*, 1995; Fernandez-Figares *et al.*, 2000). Although most of the triticale fields have this end-use, farmers familiar with the crop are increasingly focussing on alternative and specific uses. On the other hand, marketing problems are frequent for the growers when trying to sell their triticale grain, and often when they find a purchaser, the prices received are lower than for bread wheat, but similar to those for barley or rye for feed.

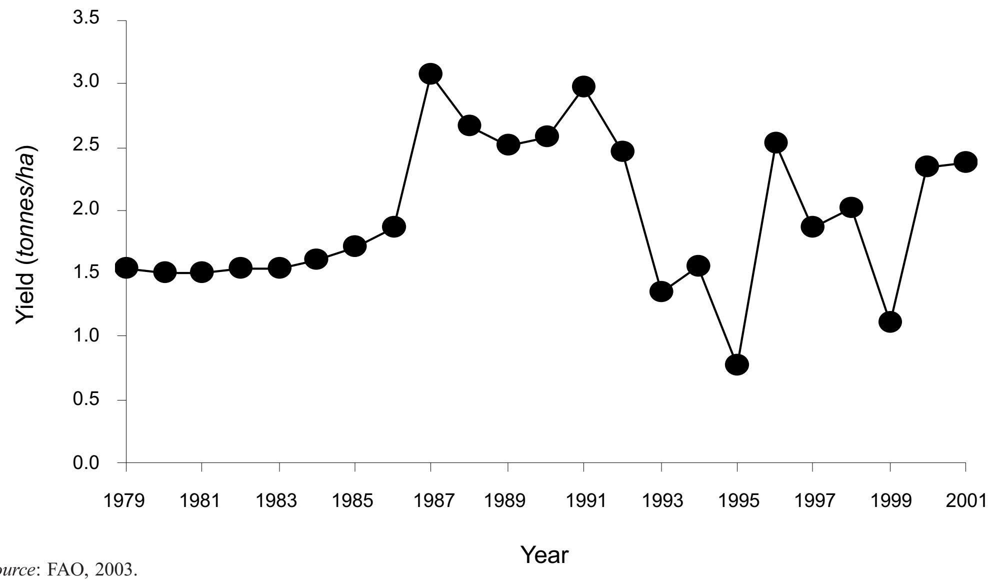
In some meadows of Extremadura and Andalusia, triticale is grown as an intercrop in ilex fields, for pig or sheep grazing, providing green forage or mature spikes. Conversely, in the cereal-producing areas of northeastern Spain, with an average rainfall during the crop season (from November to July) of 500 mm and where sheep and dairy cattle are common, triticale is grown on about 1 500 ha for silage (Plate 4) in rotation with maize. Harvesting takes place about ten days after flowering in order to have enough forage production with acceptable quality (Royo *et al.*, 1998) and to avoid significant yield reductions from delayed sowing of maize, the main crop of the rotation. This practice allows farmers to grow two crops per year. The average composition from 17 analyses of silages from different farms showed 28.8 percent dry matter, 9.4 percent crude protein, 32.6 percent crude fibre, 29.4 percent acid detergent fibre, 58.2 percent neutral detergent fibre and 6.2 percent lignin (Royo and Serra,

FIGURE 1
Evolution of the area devoted to triticale and total production in Spain, 1979-2001



Source: FAO, 2003.

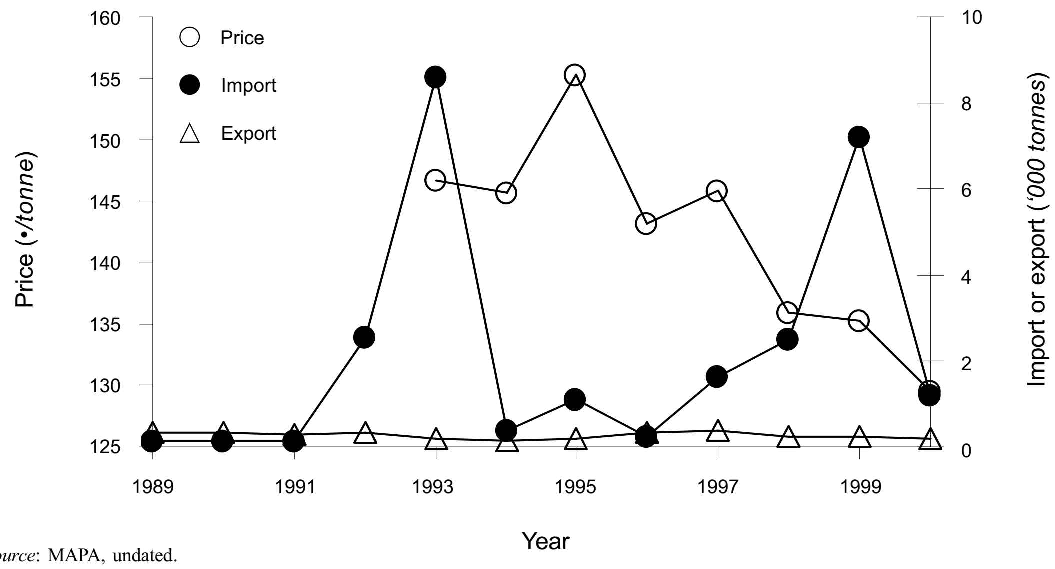
FIGURE 2
Average yield of triticale in Spain, 1979-2001



Source: FAO, 2003.

1993). Farmers agree that the advantages of triticale in rotation with maize in these areas include: (i) guaranteed forage supply during winter (triticale is grown from November to May and maize in the remaining months); (ii) higher productivity than other cereals, such as wheat or barley; (iii) less lodging and fewer diseases than barley; (iv) earlier flowering than wheat; and (v) lower water consumption than ryegrass (Royo and Aragay, 1994). Different studies conducted in the region have concluded that when triticale is the only crop grown during the year,

FIGURE 3
Price received by farmers for triticale and import and export of triticale in Spain, 1989-2000



Source: MAPA, undated.

forage has to be harvested at the late-milk/early-dough stage, because the low quality at this stage compared with earlier ones is offset by higher dry-matter yields.

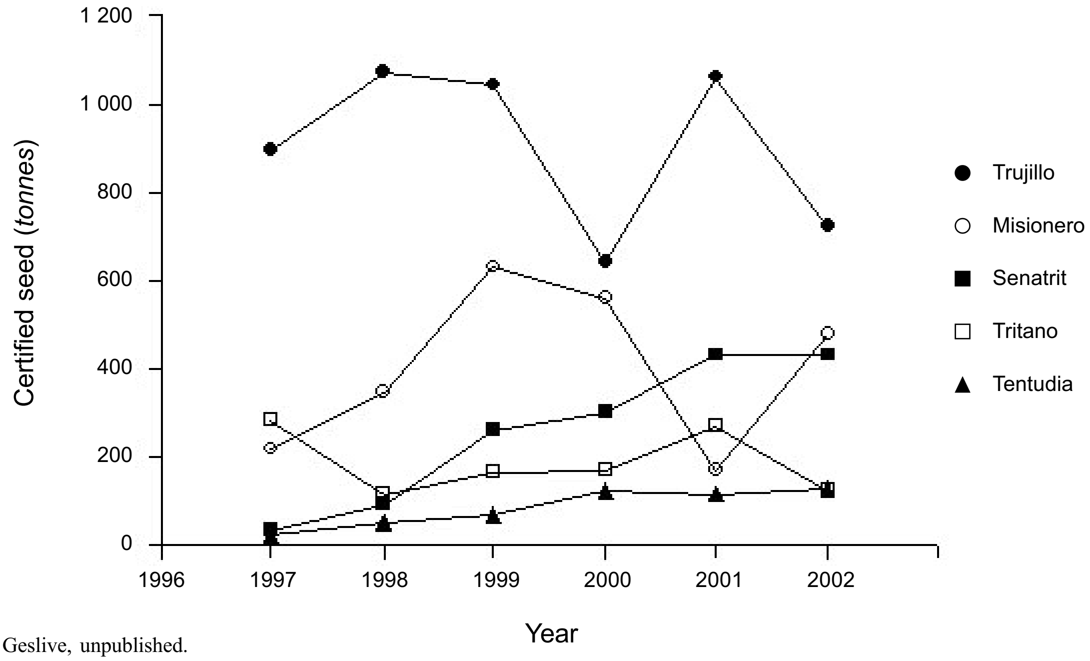
The use of triticale for dual purpose (forage and grain production in the same crop season) has been widely investigated in Spain (Royo, 1997; Royo and Tribó, 1997). This end-use is recommended when forage is needed during winter but the main objective of the field is grain production. In several experiments throughout Spain, the crude protein in the forage varied from 29.6 to 31.2 percent (showing a trend to diminish with late cuttings), the digestible crude protein varied from 24.9 to 26.3 percent and the acid detergent fibre from 17.2 to 19.8 percent (tending to increase with late cuttings) (Royo *et al.*, 1994). Early sowing is recommended when forage and grain are to be harvested in the same cropping season. To avoid drastic grain yield reductions, forage should be cut no later than the beginning of jointing, leaving intact the apical dome (Plate 5) (Royo *et al.*, 1997). Winter triticales appear to be better adapted for forage production, but the combined output of both forage and grain makes spring types seem better suited to the Mediterranean climate and to late-autumn sowing (Royo and Parés, 1996; Royo and Romagosa, 1996).

VARIETY DEVELOPMENT

In 1947, Sánchez-Monge started the first triticale breeding programme in Spain (Sánchez-Monge, 1996). He also determined that the hexaploid ploidy level of triticale was the optimal level for vigour and productivity. Cachirulo, the first Spanish triticale variety, was developed by this programme and released for production in 1969. Since then, about 50 new varieties have been released in the country, but only a few of them have reached the farmers. Germplasm from the International Maize and Wheat Improvement Center (CIMMYT) has had a strong impact on the development of new triticale varieties in Spain. Manigero and Fascal, two substituted types (rye chromosome 2R replaced by chromosome 2D of wheat), were the most cultivated varieties in the 1980s. Afterwards, a new generation of complete types (having all seven rye chromosomes), more productive and stress tolerant, was introduced. Presently, several public and private breeding programmes continue (Plate 6), and the best performing varieties are selected for demonstration trials (Plate 7) visited by farmers during field days.

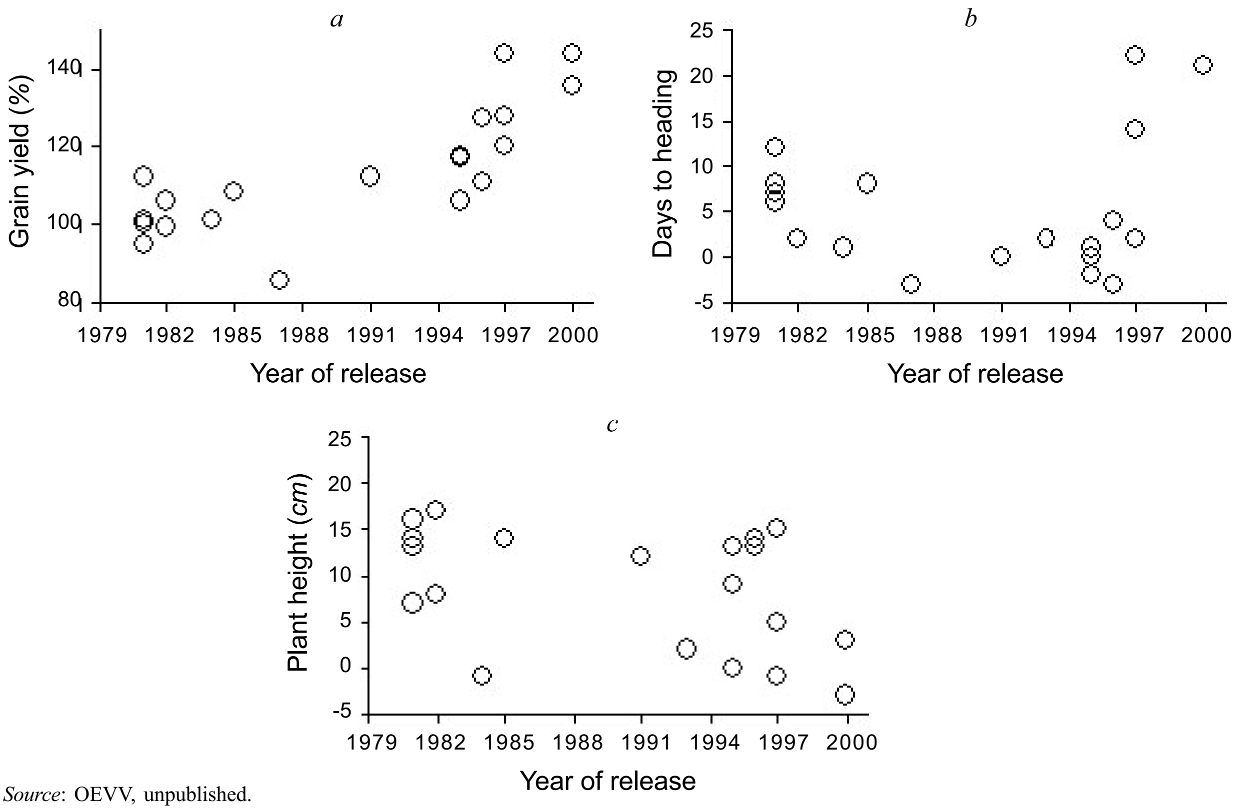
A map of the current variety structure in Spain can be determined by looking at the amount of certified seed used for each variety. The five most cultivated varieties at present are Trujillo, Misionero, Senatrit, Tritano and Tentudia (Figure 4). However, low amounts of Trijan, Galgo, Activo, Noe, Abaco, Camarma and Medellin seed were also certified in 2002. The total amount of triticale seed certified in Spain during the 2001/02 crop season was 2 553 tonnes, representing only 0.8 percent of the total certified seed of small-grain cereals.

FIGURE 4
Use of certified triticale seed in Spain, 1997-2002



Source: Geslive, unpublished.

FIGURE 5
Average yearly values for official multilocational trials of triticale genotypes released as varieties for grain yield (a), days to heading (b) and plant height (c) in relation to the check variety Manigero, 1981-2000



Source: OEVV, unpublished.

Genotype candidates to be released for cultivation must be submitted by breeders to the Oficina Española de Variedades Vegetales (OEVV), the office responsible for determining whether the candidate varieties meet the requirements to be released. The candidates are tested for two crop seasons in multilocation trials around the country. A committee evaluates annually the performance of candidates in the cooperative test network and either recommends or rejects the registration of the proposed lines. Progress in yield may be assessed by comparing the yield of the varieties released each year with the main yield of the check variety Manigero that remains stable over different crop seasons. Yield has risen mostly from 1995 onwards (Figure 5a) at an overall mean rate of 1.68 percent/year. The latest yield increases may be associated with the late-heading varieties (Figure 5b). On the other hand, recently released triticales are also shorter in height than their predecessors (Figure 5c). Important improvements have also been achieved among the released lines in 1 000 kernel weight (average gain of 2.5 percent/year), in specific grain weight (gain of 1.44 percent/year) and in protein content (gain of 1.92 percent/year).

CONCLUDING REMARKS

Triticale has a place in Spanish agriculture. However, until now its spread has been restricted by causes other than the intrinsic value of the crop. The lack of expansion of the crop, due mainly to political and commercial reasons, has compelled some Spanish institutions that traditionally conducted breeding programmes and research projects on triticale to dedicate their efforts to crops with greater market demand. Good varieties for grain production are available at present, but future efforts should concentrate on the development of triticale varieties for forage production.

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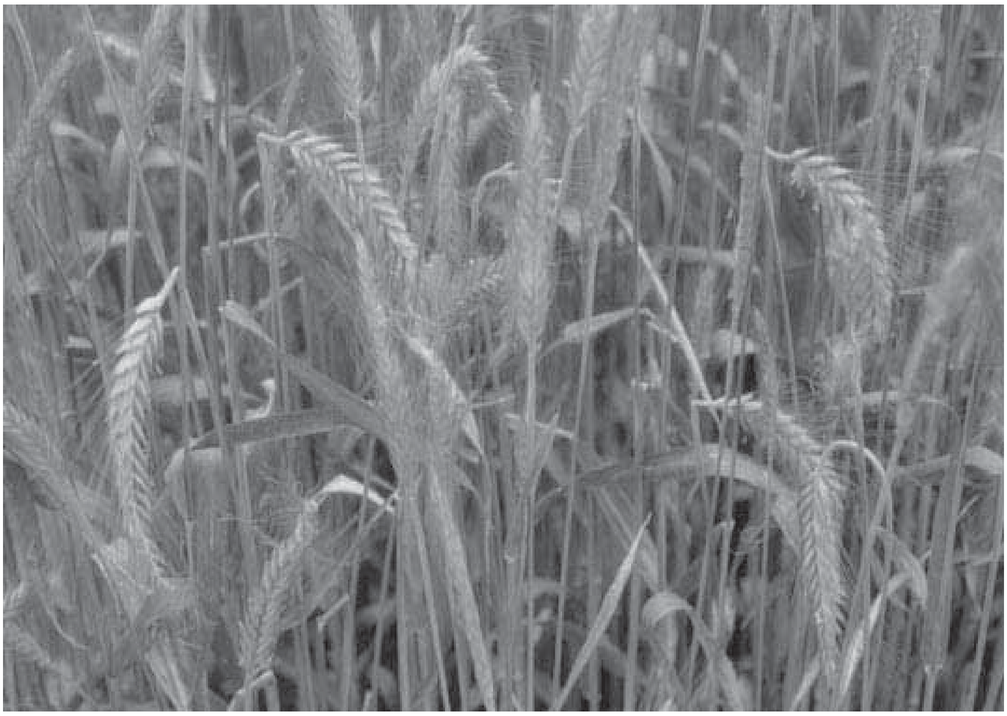
PLATE 1
Damaged triticale stems after a hail storm in Lérida, Spain
C. Royo



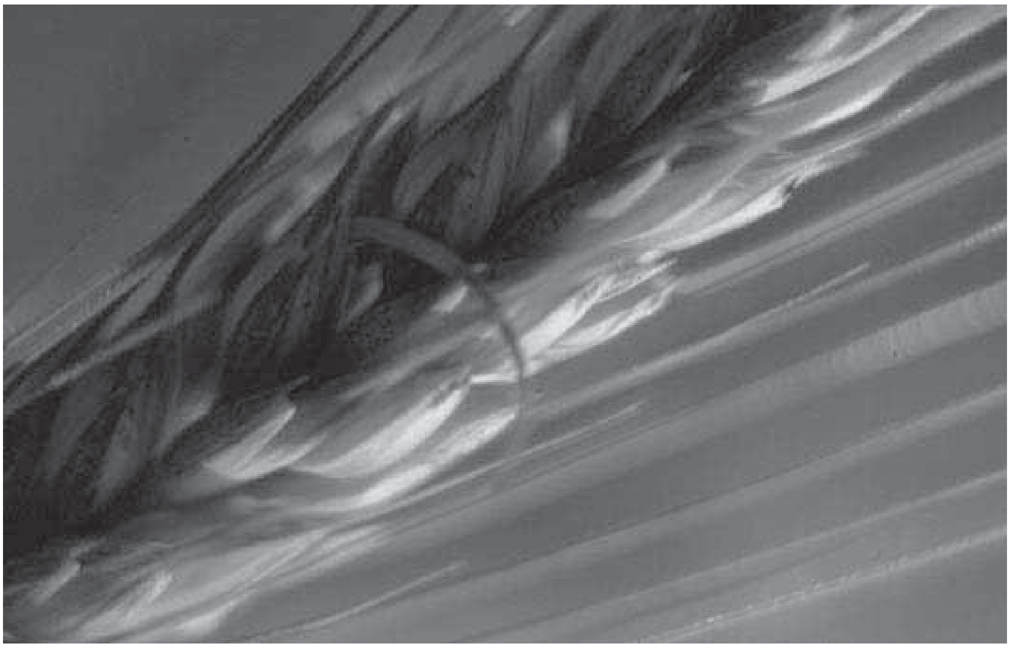


PLATE 2
Sprouting in a triticale spike due to wet conditions during grainfilling in Lérida, Spain
C. Royo

PLATE 3
Frost damage to triticale in Granada, Spain
C. Royo

PLATE 4
Triticale silo in the Alt Empordà region, Gerona, Spain
C. Royo

PLATE 5
Study conducted on the double use of triticale and barley; shorter plants have been cut and have regrown in El Palau d'Anglesola, Lérida, Spain
C. Royo

PLATE 6
F_8 lines at an IRTA triticale breeding programme in which barley rows have been used for isolation in El Palau d'Angesola, Lérida, Spain
C. Royo

PLATE 7
Triticale and wheat variety demonstration trial at IRTA Fundación Mas Badía, Gerona, Spain
C. Royo

Triticale in Turkey

S.A. Baðcý, M. Keser, S. Taner, T. Taºyürek

In Turkey, cereals are commonly grown in areas where the environmental conditions are not very suitable for these crops. Generally, in the central and southeastern Anatolia regions and in the high altitudes of other regions where a rainfed agricultural system is practiced, the possibility of growing crops other than cereals is limited. Annual average precipitation is approximately 350 mm in these regions. Because growing other crops is not economically profitable under these circumstances, compulsorily cereals are grown with low yield. The most important yield-limiting factor in these regions is a lack of water. To increase the productivity in these regions, besides using suitable varieties and growing techniques, triticale is one option for farmers, especially in areas of central and eastern Anatolia where lack of water and low temperature predominate. In these cold regions, winter-type triticale has shown comparative advantage, and recently its planting area has increased. Triticale tolerance to drought, winter and plant nutrition deficiencies is complemented by its good resistance to common cereal diseases. These advantages make triticale a good alternative to other cereals.

Triticale area in Turkey was estimated at 10 000 ha at the end of the 1990s. Nowadays, with dramatic increases, its area has reached approximately 160 000 ha, and it is becoming one of the main cereals after wheat and barley (Table 1). Since triticale is a new crop for Turkey, its end-use is not as diverse as would be expected. Current production of triticale in Turkey is used mainly in the feed industry.

TABLE 1
Harvested area, average yield and production of main small-grain cereals in Turkey, 2002

Cereal	Area (*ha*)	Yield (*kg/ha*)	Production (*tonnes*)
Wheat	9 400 000	2 128	20 000 000
Barley	3 550 000	2 085	7 400 000
Rye	135 000	1 740	235 000
Oats	150 000	1 933	290 000
Triticale[a]	160 000	2 100	336 000

[a]Estimate based on seed production and Extension Services surveys.
Source: FAO, 2002.

CROP IMPROVEMENT

The first studies on triticale in Turkey started with several international projects at universities in the 1940s. These studies focussed on testing and evaluating triticale for quality and yield. In the 1980s, university studies taking place along the coastal areas of Turkey concentrated on spring-type germplasm that came from the International Maize and Wheat Improvement Center (CIMMYT). In this germplasm, a few lines selected had better quality and yield. Winter-facultative triticale studies started at Bahri Daðdaº International Winter Cereal Research Center in Konya in the early 1990s. Triticale materials mainly from European sets and material from CIMMYT were evaluated and subjected to selection. As a result of these studies, the first triticale cultivar Tatlýcak-97 was registered in 1997. The newly released triticale, having longer spikes and more kernels per spike compared to wheat and barley, was introduced to Turkish farmers as an alternative crop in marginal areas. Farmers immediately showed great interest in triticale, and since then triticale has expanded very quickly.

Triticale improvement studies are currently being carried out at several institutes belonging to the Ministry of Agriculture – Bahri Daðdaº International Agricultural Research Institute (BDUTAE) in Konya, Anatolian Agricultural Research Institute (ATAE) in Eskiºehir and Eastern Anatolia Agricultural Research Institute (DATAE) in Erzurum – and at a few universities, such as Çukurova University in Adana. The germplasm used in these research programmes is mainly from CIMMYT material. The performance of the elite material selected from this germplasm is very promising (Table 2). Agronomy studies on triticale have been conducted at various institutes and universities.

Triticale is, in general, more tolerant than wheat and barley for biotic and abiotic stresses. Breeding for marginal areas (acidic or alkali soils), micronutrient deficiencies (copper, zinc or magnesium) or toxicity (boron) and drought stress are the main objectives of most spring- and winter-triticale breeding programmes in the world. Experiments on fertilization carried out in the Konya and Sivas regions, where triticale crops are grown widely, showed that triticale requires approximately 60 to

TABLE 2
Yields of some triticale varieties in different locations in Turkey

Genotype	Rainfed			Irrigated	
	Konya	Çumra	Obruk	Konya	Çumra
			(*kg/ha*)		
Tatlıcak-97	6 335	3 800	1 783	7 348	5 823
Melez-2001	5 540	2 765	1 517	6 728	5 063
BDMT 98/8 S	5 250	2 605	1 890	7 183	5 778
Mikham-2002	4 993	2 490	1 626	7 318	5 603
LSD (%5)	86.2	59.4	47.1	95.9	77.3
CV	11.0	12.5	19.7	8.9	9.0

Source: BDUTAE-Konya, Annual Report 2002.

TABLE 3
Overall effect of zinc application on plant productivity of various cereal species

Cereal species	Dry production (*g/plant*)		Index for zinc efficiency (*%*)	Difference (*%*)
	–Zinc	+Zinc		
Rye	0.74	0.87	85	18
Triticale	0.64	0.85	75	33
Barley	0.74	1.14	65	54
Bread wheat	0.48	0.83	58	73
Durum wheat	0.28	0.77	38	166
Oats	0.37	1.06	35	186

Source: Torun *et al*., 1998.

TABLE 4
Effects of zinc application on triticale and other cereal varieties

Variety	+Zinc (*kg/ha*)	–Zinc (*kg/ha*)	Difference (*%*)	Index for zinc efficiency (*%*)
Gerek-79	3 100	4 460	44	70
Bezostaja	1 900	4 150	118	47
Kunduru	330	2 470	648	13
Çakmak-79	170	760	347	22
Presto[a]	3 380	4 280	26	79
BDMT-19[a]	4 000	4 240	6	94
Tokak	2 240	4 770	113	47
Erginel	1 920	4 360	127	44
Aslım	3 560	3 340	-7	107
Chekota	810	1 880	132	43
LSD (%5)	59	47	-	-

[a]Triticale.
Source: Ekiz *et al*., 1998.

70 kg/ha P_2O_5 and 60 to 90 kg/ha nitrogen (Baðcý, 1999) in Konya; whereas in Sivas it was found that 70 to 80 kg/ha P_2O_5 and 120 kg/ha nitrogen (Taºyürek *et al*., 2001) may be needed. The main advantage of triticale in Turkey is its high tolerance to zinc (Zn) deficiency compared to wheat, barley and oats. Zinc deficiency is one of the most important yield-limiting factors in the Konya region (Baðcý, 2000). The resistance index for Zn for rye, barley, bread wheat, durum wheat and oats was 85, 65, 58, 38 and 35 percent, respectively. The resistance index for Zn for triticale was 75 percent, second only to rye, which is a very resistant crop to zinc deficiency (Table 3) (Torun *et al*., 1998). In another study carried out on the zinc efficiency of various cereal species in Konya, it was shown again that triticale genotypes (Presto and BDMT-19) had the highest zinc resistance index after rye (Table 4) (Ekiz *et al*., 1998).

With the increase of triticale area, wheat and rye

TABLE 5
Reactions of various cereal genotypes to common root and crown rot pathogens

Genotype	Cereal	Pathogen[a]			
		Drechslera sorokiniana	*Fusarium culmorum*	*Fusarium moniliforme*	*Rhizoctonia cerealis*
Bezostaja-1	Bread wheat	18.9 MR	33.3 MR	30.6 MR	18.6 MR
Haymana-79	Bread wheat	73.4 S	66.3 MS	65.0 MS	73.7 S
Gün-91	Bread wheat	38.9 MR	38.1 MR	12.6 R	41.9 MR
Dağdaş-94	Bread wheat	39.0 MR	7.9 R	17.6 MR	24.6 MR
Kınacı-97	Bread wheat	23.9 MR	11.5 R	21.0 MR	20.9 MR
Selçuklu-97	Durum wheat	22.4 MR	18.7 MR	18.0 MR	13.6 R
Erginel-90	Barley	81.0 S	40.0 MR	70.0 MS	27.2 MR
Aslım-95	Rye	6.5 R	13.3 R	12.1 R	8.1 R
Tatlıcak-97	Triticale	12.1 R	14.0 R	6.9 R	10.9 R
BDMT-19	Triticale	7.7 R	9.9 R	7.7 R	6.0 R

[a]R = resistant; S = susceptible; M = medium.
Source: Aktaº *et al*., 1997.

diseases and insects could be a potential problem for triticale (El Harrak, Mergoum and Saadaoui, 1998). It has been reported that triticale is tolerant to rusts (*Puccinia* sp.), *Septoria tritici*, smuts (*Ustilago* sp. and *Urocystis* sp.), bunt (*Tilletia* sp., *Neovossia* sp.), powdery mildew (*Blumeria graminis*), take-all (*Gaeumannomyces graminis*), root rots, cereal cyst nematode (*Heterodera avenae*), Russian wheat aphid (*Diuraphis noxia*), barley yellow dwarf virus, wheat mosaic virus and barley stripe mosaic virus (Varughese, Pfeiffer and Peña, 1996). However, it has been shown that in North Africa (Mergoum, 1994) under severe infestation with Hessian fly (*Mayetiola destructor*) and dry conditions many triticale genotypes were susceptible to attacks by this insect. Similarly, in Mexico, a new race of stripe rust (*Puccinia striiformis*) that overcame the *Yr9* gene of resistance caused severe damage on more than 20 percent of CIMMYT germplasm at the Toluca CIMMYT Station during the summer of 1996 (Mergoum *et al.*, 1998). Triticale has also been reported not to have enough resistance against *Fusarium* sp., *Septoria nodorum*, *Helminthosporium* sp., eyespot (*Cercosporella herpotrichoides*) and bacterial diseases (*Xanthomonas* sp. and *Pseudomonas* sp.). Developing tolerance in triticale against these diseases should be a prime objective. Triticale tolerance to ergot is greater than in rye, and in some cases, this tolerance has come about through an increase in triticale productivity.

Diseases have not been a major problem for triticale in regions where triticale is widely grown in Turkey. In disease tests, it has been seen that triticale has enough tolerance to the diseases prominent on wheat. Variety Tatlýcak-97 was more tolerant to *Fusarium culmorum*, *Drechslera sorokiniana*, *Fusarium moniliforme* and *Rhizoctonia cerealis*, which are the most common pathogens of root and crown rot diseases in Konya, than other wheat and barley varieties in the same experiment (Table 5) (Aktaº *et al.*, 1997). In another study, wheat, barley and triticale lines were tested using root and crown rot pathogens, in particular *Drechslera sorokiniana*, *Fusarium culmorum* and *Fusarium avenaceum*. Tolerance/resistance percentages were 28, 7, 6 and 88 percent for lines developed for rainfed conditions, irrigated conditions, triticale lines and barley, respectively (Baðcý *et al.*, 2001).

TRITICALE VARIETIES AND SEED PRODUCTION

Six triticale varieties have been registered in Turkey. Five of them are winter-facultative types. Tatlýcak-97, Melez-2001 and Mikham-2002 were developed by the Bahri Daðdaº International Agricultural Research Institute and Karma-2000 and Presto by the Anatolian Agricultural Research Institute (Table 6). These varieties are mostly grown in rainfed, winter-facultative, cereal-growing areas. The most widely grown triticale variety in Turkey is Tatlýcak-97. Although it is grown across the country, Tatlýcak-97 is widely cultivated in the Konya, Sivas, Tokat, Afyon, Aydýn, Bolu, Aksaray, Sinop, Tekirdað and Kars regions. Tacettinbey, developed by the College of Agriculture at Çukurova University, is a spring type. This variety is recommended for the coastal regions of the country, especially the Mediterranean zones.

Seed production in Turkey has been the responsibility of the institutions that develop the variety and the State Farms (Table 7). Each institute has the responsibility of producing breeder and basic seed and giving the seed to State Farms, which produce certified seed.

TABLE 6
Triticale varieties released in Turkey and some of their characteristics

Variety	Registration (*year*)	Growth habit	Yield (*kg/ha*)	'000 kernel weight (*g*)	Test weight (*kg/hl*)	Protein (*%*)
Tatlıcak-97	1997	Winter	3 560	36-39	75	12-14
Melez-2001	2001	Winter	3 350	36	68	11-12
Karma-2000	2000	Winter	3 350	33-43	74-78	10-12
Presto	2000	Winter	3 340	22-23	76	11-12
Mikham-2002	2002	Winter	5 930	38-39	73-74	12
Tacettinbey	1999	Spring	7 150	40-46	73-75	11-13

Source: Anonymous, 1999, 2000, 2001, 2002.

TABLE 7
Seed production of triticale varieties, 2001-2002

Variety	2001 (*tonnes*)	2002 (*tonnes*)	Institute or State Farm[a]
Tatlıcak-97	255	377	BDUTAE, TİM
Melez-2001	-	10	BDUTAE
Mikham-2002	-	2	BDUTAE
Karma-2000	-	10	ATAE
Presto	-	11	ATAE
Tacettinbey	50	50	ÇÜZF
Total	305	460	

[a]BDUTAE = Bahri Daðdaº International Agricultural Research Institute; TÝM = State Farm; ATAE = Anatolian Agricultural Research Institute, ÇÜZF = College of Agriculture, Çukurova University.

TRITICALE USE

Triticale is used for different purposes, in particular for feed as grain, hay and silage. Although triticale is grown as a silage crop by farmers, it is also planted in mixture with other forage crops. Triticale is used as grain especially for poultry. Triticale can be used in rations as a protein resource replacing other cereals (Belaid, 1994). In rations where triticale replaced maize, it was reported that increasing the triticale ratio positively affected egg productivity up to 40 percent (Table 8) (Azman *et al.*, 1997).

Triticale flour can also be used to replace soft wheat flour in mixture in breads, cakes or cookies. In a study involving different mixture ratios of Tatlýcak-97 triticale and Gerek-79 bread wheat with Bezostaja-1 (1:1), total protein, raw ash amount, amylase activity, Zeleny sedimentation value, Alveogram resistance and energy increased, but gluten index and falling number value decreased (Table 9) (Elgün, Türker and Baðcý, 1996). In some regions of Turkey, up to 30 percent triticale flour is used in mixture with wheat flour for bread making. In addition, triticale is used in some villages to make flat bread.

CONCLUDING REMARKS

Although triticale is a new crop for Turkish farmers, it has been well accepted, and its dissemination is much faster than a new wheat or barley cultivar. Triticale growing area is rapidly increasing in the Anatolia plateau where cereal production (wheat in particular) is limited by some biotic and abiotic factors. Triticale has resistance/tolerance to most known stresses in the Anatolia region. Because of the low nutritional value of rye and the low yield of oats, triticale has been spreading rapidly in areas where wheat yield is limited. Creating new opportunities for triticale by developing new triticale cultivars that meet farmer and consumer preferences and needs, triticale production will continue to increase. Triticale, with all of its advantages, promises to be a real alternative crop for Turkish farmers.

TABLE 8
Effects on egg productivity of adding triticale to feed rations

Ration[a]	Egg productivity (*%*)	Egg weight (*g*)	Feed consumption (*g*)
% 0 triticale	63.22 ± 4.02	60.71 ± 0.69	98.46 ± 1.56
% 10 triticale	64.78 ± 3.01	59.54 ± 0.98	94.91 ± 4.04
% 20 triticale	65.13 ± 3.24	59.16 ± 0.69	98.45 ± 1.06
% 40 triticale	69.04 ± 3.40	59.30 ± 0.79	97.03 ± 3.46

[a]Control ration includes 62 percent maize.
Source: Azman *et al.*, 1997.

TABLE 9
Effects on some quality traits of triticale flour in mixture[a]

Mixture Bez : (Grk+Ttl)	Moisture (%)	Total protein (%)	Raw ash (%)	Zeleny sed. (*ml*)	Wet gluten (%)	Gluten index (%)	Falling number (*sn*)
100 : (100 + 00)	14.5	9.4c	0.50e	24.1c	30.5	57.9a	428a
100 : (75 + 25)	14.5	9.8bc	0.51d	25.9bc	30.9	51.2ab	413ab
100 : (50 + 50)	14.5	10.1abc	0.52c	27.5ab	31.6	48.0b	405ab
100 : (25 + 75)	14.5	10.5ab	0.53b	28.2ab	31.8	50.3ab	394b
100 : (00 + 100)	14.5	10.9a	0.54a	29.7a	32.0	46.6b	369c
LSD	-	0.88*	**	4.03**	ns	8.74*	23.8*
Bezostaja-1	15.6	10.0	0.54	30.4	33.0	59.3	566
Gerek-79	13.6	8.8	0.46	22.0	29.0	47.4	392
Tatlıcak-97	13.3	11.7	0.55	26.5	31.6	31.7	321

[a]Significant at $p<0.05$ represented by *; significant at $p<0.01$ represented by **; ns = non-significant. Numbers with different letters are significantly different.
Source: Elgün, Türker and Baðcý, 1996.

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