T R I T I C A L E

PAPER TO THE ROYAL SOCIETY OF HEALTH AND THE SOCIETY OF CHEMICAL INDUSTRY

8 JANUARY 1976

By: Joseph H. Hulse
Director, Agriculture, Food and Nutrition Sciences
International Development Research Centre, Canada

Triticale is a hybrid produced by an intergeneric cross between the cereals wheat and rye. The name "Triticale" is derived from a combination of Triticum and Secale, the generic names of wheat and rye respectively. Triticale is the only known hybrid of two cereal genera that is being produced as a commercial crop. "Triticale" should be regarded as the common name for wheat and rye hybrids; the official botanical name will probably be decided at a future meeting of the International Botanical Congress. Whatever is the generic name eventually chosen, Triticale must be regarded as a genus that already displays a wide range of genetic diversity.

The first recorded wheat x rye hybrid was reported in 1873 by a Scottish plant scientist, A. Stephen Wilson, in the Transactions of the Botanical Society of Edinburgh. Wilson tried to synthesize hybrids between several pairs of cereal grains including wheat, rye, barley and oats. Wilson first emasculated the wheat plant by removing the anthers, then, with a camel hair brush, he applie the pollen from the rye plant onto the stigma of wheat. Most of Wilson's crosses never vegetated and of all the combinations he attempted, only two crosses between wheat and rye produced what appeared to be a true hybrid. The culm and ear of two plants produced from wheat ovules and rye pollen displayed characteristics intermediate between the two parents. Unfortunately, as Wilson somewhat sadly reported, his hybrid plants were absolutely barren "not a single kernel having been produced".

During the 50 years following Wilson's experiments, several reports of wheat and rye hybrids were published. During the 1880's E.S. Carmen, the Editor of "The Rural NewYorker" described a true hybrid from several wheat x rye crosses. In 1889, W. Rimpau in Germany recorded the first account of a spontaneously occurring, partially fertile wheat x rye hybrid.

In 1918, at the agricultural experimental station at Saratov in Russia, several thousand naturally occurring wheat x rye hybrids were reported by Meister and his colleagues. In one experimental wheat area, some 20% of the plants appeared as hybrids, most of them derived from early maturing wheat varieties. The research at Saratov is the most significant of the early wheat x rye hybridization experiments and its abrupt termination may well be attributable to the dominance of the Lysenko philosophy. All of the Saratov hybrids were male sterile and incapable of self-pollenation. This mule-like inability to reproduce themselves was characteristic of virtually all the wheat x rye hybrids produced until the late 1960's.

About the time the research at Saratov was coming to an end, the search for a fertile wheat x rye hybrid was taken up by Dr. Arne Muntzing at the Institute of Genetics in Sweden. It is from Muntzing that we first learn the name "triticale" which he attributes to Dr. Erich Tschermak of the Muncheberg Institute for Plant Breeding Research.

Muntzing described his earliest triticale plants as "only theoretical curiosities" but his diligent efforts did produce triticale plants which on light and sandy soils gave yields (weight of grain per unit area of land) roughly equal to those of locally established wheat varieties. Muntzing however reported several undesirable properties in addition to the persistent and characteristic infertility. Muntzing described excessively tall triticale plants, possibly a manifestation of hybrid vigor, and malformed shrivelled seeds. The tall plants tended to collapse, or lodge, with increasing nitrogen fertilization: the shrivelled seeds contained inadequately filled-out endosperms. Nevertheless, in 1939, Muntzing predicted that the wide genetic variability theoretically available among triticale hybrids would in the fullness of time enable scientists to overcome these unsatisfactory attributes.

More than 30 years passed before Muntzing's prediction was realized through a project, the description of which constitutes the main body of this paper.

Genetic incompatability between partners of an intergeneric hybridization process is a matter of common experience. The consequence of this incompatability is that the first generation hybrid seedling is infertile and carries only a single set of wheat chromosomes and a single set of rye chromosomes. The two sets of chromosomes cannot pair for the purpose of sexual reproduction and no offspring can result.

....4

In 1937, Pierre Givaudon, a French scientist, discovered that the treatment of seedlings with colchicine causes the chromosomes to double. Colchicine is an alkaloid derived from the genus Colchicum which includes the autumn crocus. It was this discovery, together with an adventitious outcross which I shall describe later, which opened the door for the metamorphosis of triticale from a laboratory curiosity into a potential food crop.

Modern techniques of embryo culture have also contributed to triticale's present state of development. Because of the comparative incompatability of the parental species, the hybrid embryos do not always develop normally. Their chances of survival can however be increased by removing each embryo from its seed about two weeks after pollination and transferring it to a nutrient agar gel. When the roots and shoots have begun to develop, the plant is potted in soil and subsequently treated with colchicine.

The most extensive and productive triticale research program is a cooperative undertaking between the Centro Internacional de Mejoramiento de Maiz y Trigo in Mexico (CIMMYT), the University of Manitoba and the University of Guelph in Canada. The Canadian program began in the mid-1950s with a collection of primary triticales from all over the world. During the early 1960s, the most promising primaries were crossed to produce secondary triticales. In 1963, in order to grow two plant generations within a year, the University of Manitoba established a winter nursery at Ciudad Obregon in Mexico.

....5

The Manitoba Mexican nursery attracted the attention of Norman Borlaug at CIMMYT who decided to start a modest triticale research program. Though the Mexican progeny of the Manitoba triticales produced large heads, they also displayed the undesirable characteristics reported by earlier workers including excessive tallness leading to lodging, shrivelled and sterile seed.

Nevertheless, the potential value of a cereal hybrid combining the superior physico-chemical properties of wheat with the tolerance of rye to low temperatures, and other adverse conditions, was sufficient to encourage the Canadian International Development Agency and the International Development Research Centre to invest in what we now call "The Triticale Project". The aim of the project was to produce a highly nutritious cereal grain which would out-perform the traditional cereal grains in terms of yield and tolerance to adverse factors on what might be termed 'marginal' lands. These include light, sandy and acid soils, and high altitude regions such as are to be found in the Himalayas, a number of countries of Africa, the Mediterranean, the Near East and Latin America. It must be emphasized that the Triticale Project is intended to serve the less developed nations of the world rather than privileged members of North American and European societies.

The Triticale Project began in late 1970 when the International Development Research Centre entered into a contract with CIMMYT to provide $2.5 million over a period of five years for the further development and improvement of triticale. At the same time, the first of a series of contracts with Canadian institutions was entered into with the University of Manitoba. Altogether $750,000 has been

....6

provided to Canadian institutions over the same five year period.

Throughout its life, the Triticale Project has been monitored by an Advisory Committee composed of two scientists from CIMMYT, one from each of the cooperating Canadian institutions, and three independent scientists. The Advisory Committee has met each year to review the progress made.

The overall purpose of the project was to increase the supply of edible nutritious cereal grains for the people of the less developed countries. Specifically, it was agreed that the cooperating partners would seek to create a wider genetic variability in triticale, as a means of increasing yields, improving seed quality by eliminating shrivelling, introducing dwarfing and increased straw strength to overcome lodging, improving the resistance to various diseases such as rust, smut and ergot, and the breeding and selection of triticales adaptable to a wide range of agro-climatic conditions.

Because of its large and diverse pool of wheat germ plasm, it was decided that the CIMMYT scientists would concentrate upon developing and testing new genetic combinations. The University would refine the techniques to increase the number of viable crosses; seek out genotypes less sensitive to day length and with characteristics such as cold tolerance and resistance to smut, rust and ergot. The Manitoba scientists would address the biochemical and physiological factors related to infertility and shrivelled seed. Because of its exceptional experience in Canada with winter wheats, the University of Guelph accepted the responsibility for the synthesis and development of triticales displaying a winter habit.

....7

At its outset in 1970, the Triticale Project was greeted with skepticism from several quarters. We were considered either excessively brave or foolish for investing so much money and effort into what could be described as a "very long shot".

Terence tells us that "fortune aids the brave", and Ben Johnson that "fortune favors fools". Whichever; the project at its outset was indeed favored by a remarkable piece of good fortune. In the words of Norman Borlaug, "a promiscuous outcross" occurred, in which a tall, male-sterile triticale plant was fertilized by a stray grain of pollen probably blown across the road from a dwarf bread wheat growing on the other side. The progeny of this chance mating were much shorter than their triticale mother. Most important, however, the offspring two generations later displayed inheritable fertility. Thus more than one hundred years after Stephen Wilson's first wheat x rye hybreds, the triticale fertility barrier had been penetrated.

If Norman Borlaug were a genealogist of royalty, he would probably have named this serendipitous love-child: "Fitz-rye". Instead, he called it Armadillo. The fertility of Armadillo has been transferred to the vast bulk of new triticale cultivars.

The progress made during the Project's short life is best illustrated by comparing the state of the art in 1970 with the results from the 1975 crop. A measure of the degree to which the genetic variability has been broadened is indicated by the fact that in 1970, only one new triticale plant was successfully

....8

embryo cultured and the chromosome number doubled. By 1973, chromosome doubling had been achieved in some 3,200 cultured plants. As can be seen from the following slide, in 1970 both the yields and the test weights of the ten best triticales were significantly lower than those of the ten best wheats grown at CIMMYT. The test weight is to all intents and purposes a measure of the bulk density of the grain and the lower the test weight, the larger the number of shrivelled and under-developed kernels. By 1975 however, the ten best triticales were slightly out-yielding the ten best wheats and though the average test weight of the ten best triticales is significantly lower than the average of the ten best wheats, the triticales of highest test weight, 83 kg/hl, are very close to the wheat average of 85 kg/hl.

Fertility in the new triticales has reached a level of 92% compared with the CIMMYT wheats at 97%, and the CIMMYT scientists now believe that inheritable fertility is no longer a cause for major concern. Lodging has been largely offset through the introduction of both wheat and rye dwarfing genes together with stiffer strawed parental varieties.

The best triticales are more resistant than wheat to rust and triticales are resistant to most of the major diseases which attack wheat with the exception of ergot and possibly Fusarium head blight.

Susceptibility to ergot, the matter of greatest concern, is being tackled in a unique program at the University of Manitoba.

....9

They are seeking first, to identify resistant strains of triticale, spring and durum wheats, second to determine the variability in virulence of various ergot fungi and third, to elucidate the histological basis of ergot resistance.

One finding which has emerged is that different isolates of Claviceps purpurea, the fungus responsible for ergot, vary greatly in their virulence. The pathologists at Manitoba have isolated some 30 of the most virulent ergot strains with which all of the available wheat and triticale varieties are being inoculated. Over the past five years, they have identified several wheat varieties which are resistant to all of the most virulent ergots and several others which exhibit good resistance to most of the virulent ergots. There is modest cause for optimism that this large scale screening program at Manitoba will make possible the synthesis of triticales which combine a high degree of ergot resistance with other desirable properties. More than 200 seedlings from embryos cultured from ergot resistant crosses have been propagated. The fertile Armadillo progeny show a marked improvement in resistance to ergot, probably because in the fertile genotypes there are fewer sterile florets vulnerable to infection.

COOPERATIVE RESEARCH IN DEVELOPING COUNTRIES

Triticale yield and selection nurseries have been established in more than 65 developing countries to determine the adaptability of various triticales to different environmental conditions. In addition, IDRC is financing cooperative breeding, selection and adaptability projects in India, Ethiopia, the Lebanon, Algeria, Kenya, where resistance to rust is the prime objective, Rwanda, Mexico, Colombia, and Chile. While there is still much concerning triticale's adaptability to be discovered, certain marked trends are already apparent.

Results from several countries indicate triticales are more productive than wheat on sandy soils and at high altitudes. Triticales are more tolerant than wheat to frost, low night temperatures, and also to acid and high aluminum soils. In tests in Brazil, wheats tolerated only 5 ppm whereas some of the triticales thrived at 30 ppm of aluminum.

In East Africa and Latin America, triticale displays better resistance to stem and stripe rust than the best wheats. Triticale's response to fertilizer has been limited by its past habit of growing tall and lodging. Some recent results from the CIMMYT station at Ciano in Mexico indicate that the best triticales appear to out-yield both the best bread and durum wheats at low levels of nitrogen input.

_IDE

In addition to the CIMMYT international network of nurseries, IDRC is supporting more comprehensive selection, adaptation and utilization studies in a number of countries including India, Ethiopia and Chile.

In India, work is being carried on at G.B. Pant University and on farms in the Himalayas at altitudes between 6,000 and 10,000 feet. In all cases where it is grown at high altitudes, triticale performs better than wheat both in terms of yield and protein content.

SLIDE

....11

CHEMICAL COMPOSITION AND NUTRITIONAL QUALITY

The main component of triticale is starch. The starch content of flours derived from triticale is not significantly different from its parents wheat and rye. The most striking difference in triticale is its low, hot paste viscosity attributable to comparatively high alpha-amylase activity. Though alpha-amylase content varies widely among triticales and is influenced by the conditions under which they are grown, alph-amylase contents in general tend to be higher than is technologically desirable. From the small amount of data available, the amylopectic:amylose ratio, starch granule density and size distribution; and the molecular weight of the amylose, do not appear to differ significantly in triticale from its wheat parent. Triticalesappear to suffer less starch damage during milling than the durum wheat parent.

From the information available, the minor carbohydrates in triticale, including simple sugars and pentosans, appear roughly similar in composition and content to the parents, with the exception that reducing sugars are higher in triticales which display a high alpha-amylase content.

From the scanty evidence available, the bound and free lipid content of triticales appears to vary as much among triticales grown at different locations as between triticale and its parents.

....12

There is one piece of evidence to suggest that triticales contain more bound phospholipids than the wheat parent. Apart from minor differences amont the trace components, the fatty acid compositions of such triticale lipids as have been analyzed did not vary significantly from their wheat parents, the dominant fatty acid in all cases being linoleic, followed by palmitic, oleic and linolenic.

The distribution of minerals among the major fractions of the triticale seed do not appear significantly different from what is generally found in wheat. Most of the data available indicates the total mineral content appears higher on a percentage basis in triticale than in wheat, probably attributable to the higher proportion of bran present in the incompletely filled triticale seeds. One worker reported that the iron content of triticale flour was significantly higher than that of the parent wheat. This result may be attributable more to a difference in extraction rate during milling than to an intrinsic difference.

Too little is published to make any reliable evaluation of the vitamin content of triticale but such evidence as exists suggests that triticales are not inferior in ribflovan, thiamin, niacin and alpha-tocopherol to wheat and rye.

It is the protein content and composition of triticale that offers greatest nutritional promist and that has aroused greatest skepticism. The disbelief originated when certain earlier workers announced that triticale contained protein contents in excess of 20%.

....13

As this audience is aware, the protein content of cereals such as wheat and rye is customarily determined by multiplying the Kjeldahl nitrogen figure by 5.7 and expressing the results on a 14% moisture content basis.

On reviewing some of the early triticale analyses, it was discovered that a conversion factor of 6.25 had been used and the results expressed on a dry weight basis. This unconventional calculation in itself raised the protein figure by roughly 30% above the result given by the accepted procedure.

In addition, the early triticales bore shrivelled seeds, with a high ratio of bran and germ to endosperm. Since the proportion of nitrogen is much higher in the bran and embryo than in the endosperm, the percentage protein on a total dry weight basis appears much higher in a shrivelled grain than in one in which the endosperm is well filled out.

As the grain quality, expressed in terms of weight per hectalitre, has improved, the average percentage protein in triticale has progressively

RAPHS

decreased. Nevertheless, both at Manitoba and in Mexico, the average protein of the triticales is levelling out at about half to 1 percent higher than the average of the world common wheat collection.

Relevant to this subject is a unique study at the University of Manitoba in which for the first time to our knowledge, approximately 3,000 inbred rye lines are being grown out and analyzed for protein content and amino acid composition. Of the first 1,000 rye lines

....14

analyzed, the highest protein value recorded was 27% and lysine contents ranged from 3 to 3.8 percent of protein. These 3,000 rye lines together with more than 20,000 bread wheat and 8,000 durum wheat lines, provide the raw material base for the synthesis of new triticale amphiploids.

It is evident that with such a vast pool, a remarkable number of combinations with an immense range of genetic diversity is possible. Of the best already grown out under a variety of conditions in Mexico, the CIMMYT workers report a few containing more than 13% protein and greater than 4% lysine. Some of the best triticale lines grown in Manitoba are producing the equivalent of 450 kg of protein per hectare compared with 340 kg for the best wheat.

Of considerable interest in terms of protein production is a study made in Mexico in which 150 triticale lines were evaluated for grain and forage use. The triticale was cut for forage four times at three week intervals before being allowed to produce grain. The ultimate grain yield was three tons per hectare; the total nitrogen generated was equivalent to more than one ton of protein per hectare.

It is of course well recognized that while the potential to produce protein nitrogen in the triticale grain is subject to genetic influcnece, and is inheritable, the amount of protein

....15

as percent dry matter actually deposited is influenced by the weight and condition of the seed and the relative proportions of the various seed fractions present. These in turn are strongly influenced by environment and agronomic conditions. Consequently, a committee sponsored by the United Nations, the International Union of Nutrition Sciences and IDRC recently recommended that in selecting for high protein genotypes, cereal plant breeders should select on the basis of mg. of nitrogen per seed rather than protein as percent total dry matter.

NUTRITIONAL EVALUATION

The biological value of triticale varieties has been assayed in a number of animals. In human feeding experiments in terms of nitrogen retention, high lysine triticales appeared superior to wheat at two levels of protein intake.

The nutritional quality of triticale protein was at first distorted by some unfortunate experiments in which the meadow vole, *Microtus pennsylvanicus* was used as the test animal. The meadow vole is essentially a forage eater and like the horse, possesses a large Caecum. The animal was chosen in preference to the rat or mouse because it is a comparatively well behaved, gentle creature which doesn't smell.

Protein efficiency ratios, the gain in body weight per weight of protein ingested, were determined using the vole, with casein as the dietary control. The voles grew much faster on triticale than they did on the control casein diet and several important persons, including a very senior Canadian government official stated publically that the miracle cereal grain triticale contained protein equal in nutritional quality to egg yolk.

These statements were obviously quite incredible and therefore we retained the services of two independent investigators to compare the rate of weight gains of voles, laboratory rats and mice when fed a variety of cereals, including wheat, rye, oats and triticale. The outcome was that the vole gained weight faster on all of the cereals than it did on the standard casein diet. On the other hand, the inbred Wistar rats ranked the cereal grains according to their lysine content, with triticale appearing significantly superior in biological value to wheat.

There is a growing literature which describes the nutritional quality of triticales when fed to a variety of farm animals. Unfortunately, a number of those who report their results appear innocent of the fact that triticale is not as universally homogeneous as an analytical reagent. It is in many cases difficult to discover either the parental history or the environmental origin of the triticales under test. It is probable that many of the early triticale lines were in some degree infected with ergot. Some of the reports of, for example, reduced palatability and inferior rate of weight gain in hogs fed triticale would be consistent with ergot infection. Some authors have reported a higher than normal incidence of liver abscesses and damage to ruminal epithelium in steers fattened on high levels of triticale.

....17

On the other hand, results from feeding trials with broilers, egg layers, hogs, sheep, beef and dairy cattle suggest that where the triticale is clean, disease free and of good quality, triticale on a weight for weight basis is at least equal to and frequently better than wheat or barley in many animal rations. Nevertheless, I would emphasize that there is a need for far more careful work in the field of animal nutrition in which triticales of known origin and representing a wide spectrum of genetic diversity are compared with other grains. To this end, one would encourage the nutritionists to plan their studies in consultation with those plant scientists whose business it is to breed and select triticales for improved nutritional composition. One discerns a disposition among some research workers, notably the nutritionists and technologists, to regard triticale as a single cereal species. It is of course a genus derived from two diverse genera and therefore of itself possessing an immense genetic diversity.

There have been reports of certain anti-nutrients in triticale including principally resorcinol derivatives (reported by Wieringa 1967) and trypsin and chymotrypsin inhibitors (reported by Madl and Tsen 1974b (taken out of Lorenz' paper)).

At the University of Manitoba, alkyl resorcinols extracted from triticale were added to experimental diets up to levels of 160 mg./100 g. of diet with no evident adverse effects on the animals' performance. We have therefore tentatively concluded that the resorcinols present in triticale do not present any significant nutritional hazard.

The study of trypsins in winter triticales is going on at the University of Guelph but so far it would appear that the levels are significantly lower than one finds in soya beans and since they are in large measure themolabile they are not likely to be of major nutritional consequence.

THE TECHNOLOGY OF TRITICALE

The first encouragement to triticale research in Canada came from the distilling industry through a grant from the Bronfman Foundation. Of the triticale grown in Canada which is not used in animal feed, most goes to the malting and distilling industries. Triticales grown at a number of locations in the U.S.A. are reported to have excellent malting properties and to be higher than malting barley in total extract, enzymatic activity and protein solutility. Beers produced from thw worts of triticales grown in Texas, North Dakota and Manitoba displayed satisfactory clarity and gas stability.

As one would anticipate, bearing in mind the low test weights and high proportion of shrivelled kernels, milling yields from triticales are lower and the ash content of straign grade flours are higher than those from good quality wheat. Some triticale flours appear responsive to fine grinding and air classification. In one study a straight grade 12.0% protein triticale flour, fine ground in a pinmill and air classified produced a 25% yield of a 29% protein flour and a 65% yield of a 5.5% protein flour; equivalent to a total protein shift of 73%.

....19

When judged by the North American cereal technologists' criteria of loaf volume, crumb color and texture, triticale bread, made by a conventional fermentation process, would be considered inferior to top quality wheat bread. For those who are not displeased by a slightly off-white crumb color and a mild rye flavor, the University of Manitoba has demonstrated that a very good bread can be produced from 100% triticale flour using a modified Chorleywood mechanical development process.

Triticale has been converted to a variety of alimentary pastes; rolled, extruded and puffed breakfast cereals; cocktail snacks, pancakes and various sorts of biscuits. In the United States, it appears that triticale is already finding its way into the somewhat dubious but highly profitable health food market.

The Triticale Project, however, as I have already stated, is not primarily intended to satisfy the demands of North Americans. Its purpose is to provide more food for the people of Africa, Asia, the Near East and Latin America. The vast majority of these peoples are more accustomed to flat breads than to the Wonder Loaf or Mother's Pride.

In the regions of relevance, the substitution of triticale for traditional cereals in chapatti, and tortilla appears very promising. In Ethiopia, there is considerable optimism that the native teff can be replaced by up to 70% of locally grown triticale flours in the national enjera bread.

....20

To encourage a wider technological evaluation of triticales, the International Union of Food Science and Technology (IUFoST) has created an international committee on triticale in which food technologists in a number of countries will be cooperating.

The first issue of triticale abstracts produced by the Commonwealth Agricultural Bureau is now in the course of production and will be freely distributed to all triticale workers in developing countries. We are discussing with the University of Manitoba the regular publication of a triticale newsletter to provide plant scientists, food and nutrition scientists and technologists, and others interested, with an up-to-date account of progress in triticale research and development. These publications, it is hoped, will present a balanced, sober account of triticale's virtues and imperfections and will serve to offset some of the more extravagant promotions of "the new miracle grain" and "super health food".

2 December 1975

TRITICALE BIBLIOGRAPHY

BRIGGLE, L.W. 1969. Triticale - a review. Crop Science 9(2): 197-202

HULSE, J.H. and LAING, E.M. 1974. "Nutritive Value of Triticale Protein". International Development Research Centre, Ottawa Canada

HULSE, J.H. and SPURGEON, D.C. 1974. Triticale. Scientific American 231(2): 72-80

HULSE, J.H. 1975. Triticale. Encyclopaedia Universalis. 427-429

KISS, A. 1968. Triticale. Mezogazdasagi Kiado, Budapest.

LORENZ, K. 1974. The History, Development, and Utilization of Triticale. CRC Critical Reviews in Food Technology. 5(2): 175-280

TSEN, C.C. (ed.) 1974. Triticale:First Man-Made Cereal. American Association of Cereal Chemists.

WILSON, A.S. 1873. Wheat and Rye Hybrids. Transactions of the Edinburgh Botanical Society. 12: 286-288

ZILLINSKY, F.J. 1973. Triticale breeding and research at CIMMYT. Research Bulletin No. 24. Centro Internacional de Mejoramiento de Maiz y Trigo, Mexico 6.

ZILLINSKY, F.J. and BORLAUG, N.E. 1971. Progress in developing triticale as an economic crop. Research Bulletin No. 17. Centro International de Mejoramiento de Maiz y Trigo, Mexico 6. 27p.

ZILLINSKY, F.J. and BORLAUG, N.E. 1971. Search for a new food source for man: triticale research in Mexico. Agricultural Science Review 9(4): 28-35.