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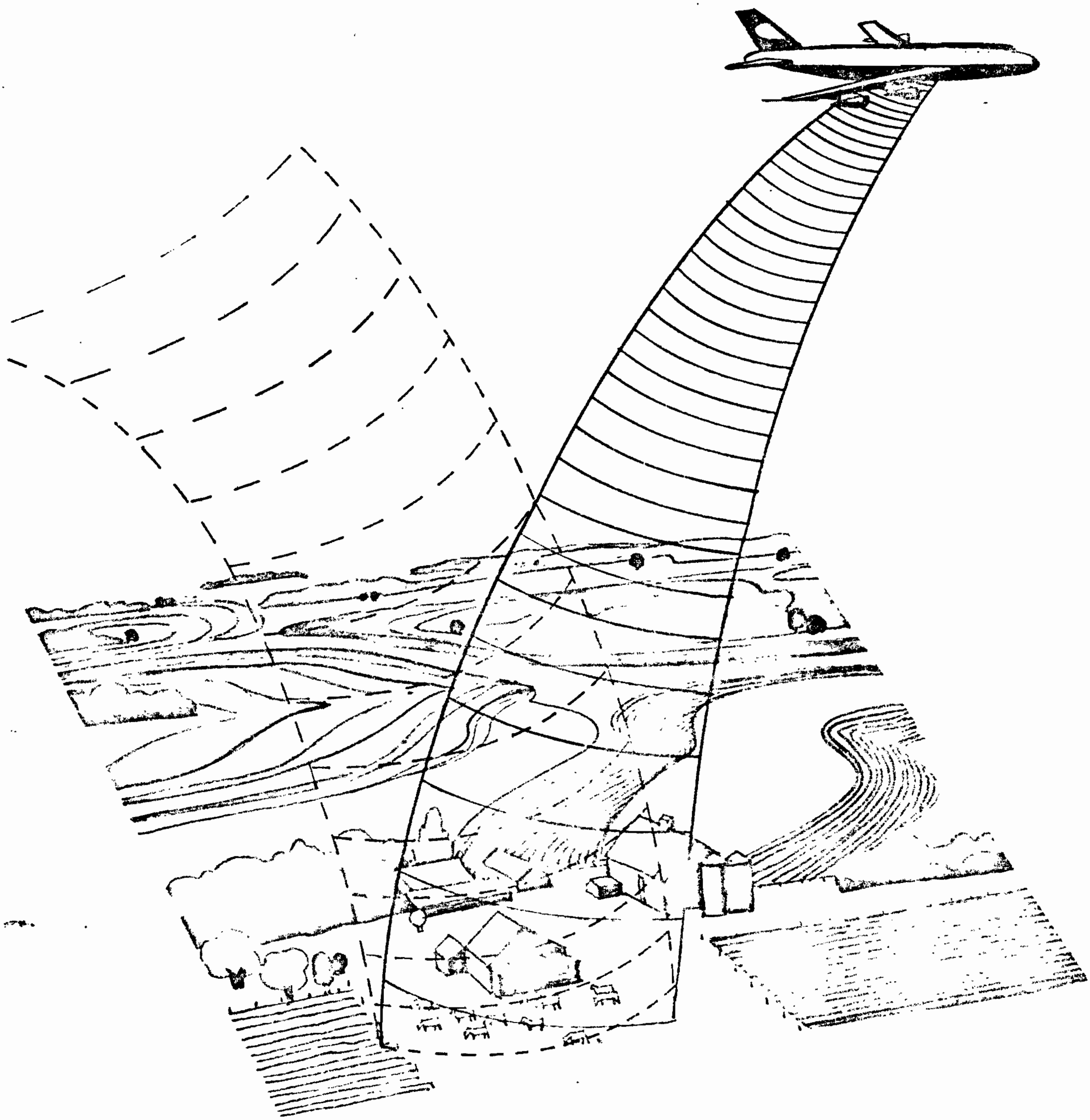

Search for a New Food Source for Man

TRITICALE RESEARCH IN MEXICO

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ONE of the most challenging and fascinating projects in progress at CIMMYT is the triticale research program. There are two main reasons for holding this viewpoint: (1) Triticale shows promise of becoming the highest yielding of all our small grains, and (2) its nutritive value in terms of crude protein content and availability of amino acids outranks, in some cases, that of wheat and corn.

CIMMYT initiated its triticale breeding program in 1964 in cooperation with the University of Manitoba, where earlier research had led to notable improvement in growth vigor and disease resistance. However, the original triticale populations with which we started were not adapted to low-latitude areas such as Mexico. Because they required long days for normal development, plants failed to mature under the short-day conditions of Mexico. Plants grew rank and tall; the straw was too weak and lodged severely under a productive management system. They were also highly sterile. Diseases, too, were a problem. Races of leaf and stripe rust prevalent in Mexico almost completely destroyed the first triticales grown in the disease-favored environment of the Toluca nursery. The first objective of the new program, therefore, was to develop strains that would produce seed during the normal crop season and resist the predominant diseases. Some

TRITICALE is a derivative of a cross between wheat (Triticum) *and rye* (Secale). *Although this manmade cereal grain has been known since 1888, it remained more or less a biological curiosity until about 40 years ago when several scientists, notably in Europe, stepped up their research programs in an attempt to develop triticales into a commercial crop.*

It was not until 1954, however, when an intensive research program was initiated at the University of Manitoba, Winnipeg, Canada, that any marked improvement was achieved in overcoming some of the deficiencies of the early crosses. Until recently, much of the triticale research in North America was based on the Manitoba types. The triticale program at the International Maize and Wheat Improvement Center (CIM MYT)[1] *in Mexico is particularly noteworthy—not only because of the climate-related handicaps the Center had to cope with, but also because the research pattern has many of the same approaches and attitrbutes that characterized the successful development and worldwide adoption of semidwarf, high-yielding wheat. If triticale eventually attains the position of being ranked favorably along with other cereal grains,* Review *feels that the research which the authors discuss here will have made a major contribution toward that goal.*—Ed.

worthwhile gains have been achieved during the intervening eight years; yet much more research must be done before triticale can become established as a cereal crop competitive with other small grain cereals.

YIELD IMPROVEMENT

ALTHOUGH average yields among triticale lines under tests have increased substantially since we began our research program, they are not yet competitive with the best Mexican wheat varieties. The present lines of triticales have several shortcomings that must be corrected before yields can be raised to the level of the best wheats. Among these are susceptibility to lodging, low tillering capacity, endosperm shrivelling during maturity, and lack of broad adaptation. Some sterility is still present, but the reduction in yield from sterility among the better strains is now much less than from other causes.

Replicated Yield Trials

GRAIN yield in Mexico among triticale strains in the early trials (up to 1968) were only slightly more than half of the best yields of wheat varieties. A major improvement in yield occurred with the selection of the more fertile types from the Cross X308, now referred to as "Armadillo" lines.

The Armadillo lines were included in replicated yield trials for the first time in the summer of 1969 at El Batan and Toluca. Average yields were well above those previously obtained at either Toluca or CIANO (Northwest Agricultural Research Center at Ciudad Obregon, Sonora, Mexico). The International Triticale Yield Nursery grown at CIANO during the winter of 1969–70 contained the best lines selected during 1968 from the Armadillo cross. The Navojoa winter 1969–70 tests contained the latest reselections from the same cross made in El Batan and Toluca in 1969. Performance of both groups improved relative to that of the wheat checks (Table 1). It is not expected that a similar degree of improvement will continue as a result of reselections from the original 308 cross. Advanced generations of progenies from crosses of Armadillo to other triticale lines and to the dwarf Mexican bread wheats are now entering yield tests for the first time. Strains selected from these populations will hopefully provide the additional increment of yield necessary to equal that of the best bread wheats.

Lodging

ALL of the highly fertile Armadillo selections which provide the basis for the major improvements in yield, seed type, and fertility in the triticale program have weak straw. This is currently one of the more serious limiting factors to higher yields. Because of a tendency to lodge, lower nitrogen application than commonly used on wheat has had to be used in the replicated triticale yield trials. An application of 60 kg/ha of actual N has been used

[1] The Center is commonly known as CIMMYT, the initials of the name in Spanish: Centro Internacional de Mejoramiento de Maiz y Trigo. Since July 1, 1971, the triticale project has been financed by the Canadian International Development Agency.

Parts of this article are based on the 1969–70 CIMMYT Annual Report and were updated where necessary.

TABLE 1.—*Average yields of the best triticale strains compared with yields of the best wheat varieties as checks in six tests*

Location and year	Triticales			Wheat checks		
	No. of strains	Ave. yield kg/ha	Yld. of top str. kg/ha	No. of checks	Ave. yield kg/ha	Yld. of top str. kg/ha
CIANO, Winter 1967–1968	22	2663	3196	3	4213	5207
Toluca, Summer 1968	23	2691	3190	...	...	...
El Batan & Toluca, Summer 1969	10	3229	3972	3	3554	3645
CIANO, Winter 1969–1970	10	4492	4990	3	5417	6202
Navojoa, Winter 1969–1970	18	5066	6282	4	5321	6491
El Batan & Toluca, Summer 1970	30	4117	5050	2	3737	4613
Navojoa, Winter 1970–71	90	5250	6320	4	5950	6600

in tests in Sonora and Toluca. At these nitrogen levels, the yields of the best triticales approached those of the bread wheat checks. However, under conditions of maximum productivity the best triticale yields barely reached 7 tons per hectare, while yields of the best bread wheats exceeded 9 tons. Little progress in maximum yields can be expected until a substantial improvement in resistance to lodging is obtained.

Breeding for improved lodging resistance is being approached in two ways: by reducing the plant height, that is, the creation of dwarf triticales; and by increasing the straw strength at the semi dwarf level. The following three sources of dwarfing are currently being used to produce the dwarfs: (1) UM940 which possesses one of the Norin 10 dwarfing genes from the Mexican bread wheat strain P4160, (2) double and triple dwarf wheats that possess Norin 10 and other sources of dwarf genes; and (3) dwarf rye (Snoopy), a selection from an out-crossing population of Gator rye.

Improvement in straw strength without resorting to additional dwarfing was undertaken because of the difficulty in maintaining high fertility and good test weight in the dwarf selections arising from crosses involving UM940.

The origin of the parental triticale stock now being used for improving lodging resistance was a bulk outcrossing population. The original selection was found to be highly heterozygous, but appears to have a heritable source of resistance to lodging which is not incompatible with fertility possessed by the Armadillo strains. The first strains from this program are expected to enter the yield tests in 1972. Dwarf selections possessing genes from dwarf rye will require at least an additional year.

Other Agronomic Factors

Tillering—Another characteristic that significantly limits yield is low tillering capacity. There is a tendency, particulary among Armadillo strains, to produce few tillers, especially among the early maturing selections. There is an apparent association between light insensitivity and reduced tillering in at least one strain of Armadillo (X308–27Y–2M–4Y–3M–0Y–0B). Light sensitive segregates require an additional two weeks to head in Sonora, but produce at least twice as many tillers under spaced seeding. In Toluca, during the summer months, both types produce heads at more or less the same time and do not appear to differ greatly in the production of tillers in this environment.

Adaptation—Current strains of triticales appear to be very restricted in adaptation. Changes in latitude, daylength, elevation, and probably many other factors influence their performance. Since triticale is a man-made species of recent origin with a narrow genetic base, it has not been subjected to selection for survival in competition with other species under numerous environmental conditions. To compensate for this lack of a natural evolution, it will be necessary to establish populations of triticales as genetically diverse as possible, and have these grown and selected in various environments around the world. The best selections from all possible sources can then be brought back together and again hybridized to establish a second cycle of more diverse material. Such a program requires the cooperation of many interested scientists around the world.

Cultural Practices—Special attention to production and cultural practices should result in better yields from the present strains of triticales in the future. Studies on the behavior of triticales under different seeding rates, row spacings, fertilizer levels and seeding dates have been initiated. Observations on the use of herbicides for weed control indicate wide differences among triticales in their reaction to herbicides. Generally, they are more sensitive than either bread wheat or durum wheat to both preemergence type herbicides and to 2,4–D.

Sprouting—Difficulties in establishing a uniform vigorous stand have been experienced on several occasions. Moist weather at maturity provokes germination in the spike. Frequently, the germination occurs before the seeds actually mature. Seeds which have started to germinate in the spike and then dry off either fail to germinate or produce very weak seedlings. Furthermore, there is a tendency for seeds harvested in a damp condition to germinate poorly, even though not sprouted. Apparently this is related to undescribed microflora adversely affecting germination.

Grain Type—Seed shrivelling is one of the major problems still unsolved in triticale improvement. After fertilization, endosperm development tends to be more or less abnormal in all triticales. The most serious abnormalities occur in the original crosses of durum and rye. It is highly possible that the failure to produce viable seeds from this cross is a direct result of abnormal development of the endosperm. Crosses between bread wheat and rye also result in badly shrivelled seeds, but an occasional seed develops sufficiently to germinate, without

Triticale Status in the U.S.

Almost all of the triticale research in North America is currently being done by the University of Manitoba, CIMMYT, and private agencies. The U.S. Department of Agriculture and the State agricultural experiment stations have restricted their efforts to plant studies, feeding trials, and field testing of varieties and experimental lines.

Commercial triticale varieties are available in the United States. Rosner, developed by the University of Manitoba, and several privately developed varieties have been marketed as seed to growers in many States. Potential new varieties are under increase for release. No official production figures are available, but scattered reports indicate that 200,000 acres, or more, were planted for harvest in 1971.

USDA and State experiment station tests show triticales have yielded from less than half that of wheat, barley, or oats to essentially the equal of these crops. Claims of extremely high relative yields have not been supported by data from State or Federal tests.

Preliminary trials indicate triticale is comparable to wheat or wheat-barley mixtures in feed value for cattle, but it seems to be less palatable than barley or wheat when fed alone. USDA has announced that triticale will not be a feed grain base crop nor will it be eligible for substitution or price support.

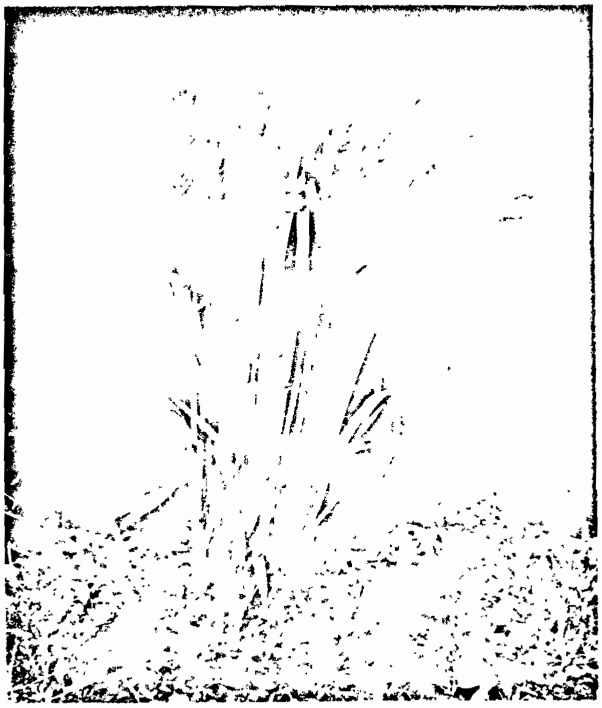
A fairly new research effort with triticale in the United States is that of utilization in the brewing industry. In preliminary tests at the USDA Barley and Malt Laboratory, Madison, Wis., the plump, protein-rich triticale yielded malts with high extract values, high ratios of wort/malt nitrogen, and high enzymatic activity, especially β-amylase. This research is being done cooperatively with the Wisconsin Agricultural Experiment Station.—Ed.

employing embryo culture. When the first amphiploids are formed following treatment of the F_1 polyhaploids with colchicine, endosperm development is more normal than in the original cross, but more irregular than in the parental species. Early generations of the amphiploids produce poorly developed seeds. Usually these seeds germinate poorly and the seedlings are low in vigor. Improvement in seed can be obtained by crossing to other triticales having the same chromosome number, particularly to strains of Armadillo, and then growing advanced generations and selecting strongly for better seed type.

From the time the program started in Mexico, the triticales have been screened continually for better grain type. The most significant improvement for plumper grain was obtained with the isolation of the highly fertile strains from cross X308 (Armadillo) in 1968. The original Armadillo selections were about 3 kilograms per hectoliter heavier in test weight than the best entries in the 1968 tests.

The most advanced crosses involving the Armadillo lines as parents are now in advanced generations in the Toluca nursery. Test weights among reselections from the original strains of Armadillo cross X308 continue to improve.

A special effort was made during the 1969–70 season to select for better seed type. A special nursery containing representative lines from all crosses still maintained in the breeding program was established at Navojoa during the 1969–70 season. This nursery contained over 5,000 head rows and was used primarily to screen for good seed types. Another nursery of bulk material maintained as an outcrossing population was also used to screen for seed type. About 4,000 single plants were harvested and the grain was examined during threshing. A third group included all populations of the segregating generations (F_3 to F_6). These were also screened for seed type. About 500 plants or lines were saved from these three sources. All samples were reexamined in the laboratory from which about 125 were retained as the best seed types to serve as a nucleus for seed improvement. They will be used in crosses to other triticales and to establish an outcrossing population within the best seeded selections.



A dwarf highly fertile and lodging-resistant F_2 plant of triticale from the cross Beavor x Armadillo growing at Toluca.

TRITICALE DISEASES

ALTHOUGH triticales appear to suffer from the same diseases as wheat and rye, diseases have not appeared to be a serious limiting factor in triticale development up to now. It is very likely that as triticale production begins on a commercial scale, those diseases which find triticale a favorable host will tend to increase to epidemic proportions. It is necessary to keep a close watch on diseases which attack this crop and breed for resistant strains in the event they become important under commercial production.

The Rusts

STEM rust, *Puccinia graminis tritici*, presents very little problem in the present triticales. Practically all stains and segregating populations in the triticale nursery are resistant. Dr. Rajaram (1969–70) inoculated 468 advanced lines and strains with two virulent strains of stem rust. Strains 15–2, 4, 7, which render the resistance possessed by Gaza durum (Sr 11), the *T. Timopheevi* gene (SrTt) and that of Yuma durum ineffective, and 151–1, 2, 3, 5, a strain highly virulent on bread wheat varieties were used because these races render ineffective many of the resistance genes now carried in both the durum and bread wheat programs. All of the lines tested were resistant. The current varieties of bread wheat and durums used in the crosses do not possess a degree of resistance equal to the resistances displayed by the triticales which were derived from these wheats. Therefore, it appears that some of the genes for resistance to stem rust must have been derived from varieties of rye.

Leaf rust, *Puccinia recondita*, appears to be much more serious than stem rust on triticales. Dr. Rajaram observed that the majority of the triticale lines tested in the greenhouse were susceptible to race 144–1, 4, 7. This race attacks Inia 66, Siete Cerros and Sonora 64. The varieties Tobari 66, Preska and Agatha are highly resistant. About half of the strains in the triticale nursery at CIANO 1969–70 were observed to have as MS to S reaction under field conditions to naturally occurring inoculum capable of infecting Inia 66 and Lerma Rojo 64. However, in yield tests and increase plots, neither the yield nor grain quality appeared to be seriously affected.

Some of the infected strains in the Navojoa nursery 1969–70 produced telia soon after the uredospores appeared. It is not known whether the environment-pathogen-race combination was particularly favorable to force this early teliospore production or whether certain triticale strains are genetically constituted to do this readily.

Stripe rust, *Puccinia glumarum*, occurs more frequently in the higher elevations near Mexico City and Toluca, than in Sonora at near sea level. Varieties of durum wheat and rye from which the triticales were originally obtained are highly susceptible to stripe rust. When the triticale program first started at CIMMYT, the triticale nursery was almost wiped out by stripe rust at Toluca. Since then, by the incorporation of resistant genes from bread wheats, durum wheats and resistant ryes, and continued screening of the segregating populations, most of the current breeding material has become resistant to the races of stripe rust occurring naturally in Mexico.

Bacterial Disease

A bacterial blight, or more characteristically a bacterial stripe, caused serious damage to many of the triticales in the nursery at Navojoa 1969–70. It had been observed on rye and triticales in 1968 and 1969, but caused very little if any damage to the infected plants. Damage from the 1969–70 infection at Navojoa indicates that the disease is capable of completely destroying a susceptible variety under conditions favorable to bacterial development.

Several strains of triticales were under increase in Navojoa during the winter of 1969–70. Some of the strains became infected in mid-January. By mid-February the most susceptible strains were completely defoliated. All highly susceptible plots were sister lines from a fertile semi-dwarf triticale strain X308–27Y. Strains from other crosses and from other sister lines of X308 were found to be resistant in neighboring plots of the same nursery. Late-maturing varieties were not infected until the plants approached heading. Environmental conditions became less favorable as the season progressed and tended to reduce the damage on late maturing and later seeded plots.

Ergot (Claviceps purpurea)

ERGOT is a serious disease of rye which also attacks triticales and other cereal crops particularly when environmental conditions tend to induce sterility. The disease is common in most temperate zone areas where rye is grown. It does not occur to any extent in Mexico. Since the ergot bodies contain a poisonous substance called ergotin, their presence in the grain is highly undesirable and prohibitive as a source of human food.

Dr. E. Larter (University of Manitoba) reported that the wheat variety Kenya Farmer was resistant to the ergot disease. Crosses between Kenya Farmer and triticale varieties were made at CIANO in March 1970 in an attempt to transfer the resistance to ergot disease from Kenya Farmer to triticales. Crosses were also made between Kenya Farmer and several varieties of rye to produce new octaploid triticales. Since the disease does not occur in Mexico, it will be necessary to do the screening for resistance in an environment more favorable for ergot development.

Other Diseases

UNDER different environments, other diseases are expected to present serious production problems. Mildew occurs commonly on wheats in Europe and many wheat-growing areas of the world. *Septoria* is also a very serious disease particularly in the Mediterranean area. Root rots take a toll of cereal crops in many grain producing areas. Many of these diseases do not occur regularly enough in Mexico to permit screening for resistance. It will be necessary to set up artificial environments to permit screening in Mexico and also to send the strains to areas where the diseases occur naturally. Cooperation is essential. Yellow dwarf, leaf blotch, necrotic spots and leaf firing occur to a limited extent on triticales at both Sonora and Toluca nurseries. These have not yet built up to damaging proportions, but should be watched as a possible source of disease problems such as occurred with bacterial stripe.

NUTRITIONAL QUALITY

TRITICALES evaluated during the past two years have proved to be a great potential source of protein and lysine. Of the 191 lines selected and evaluated from the 1969–70 small plots, protein ranged from 12.8 to 17.9 percent and lysine in the protein ranged from 2.51 to 3.84 percent. Best lines in lysine level had a protein average of 14.8 percent.

Of the 100 advanced lines of triticales from the yield tests evaluated for lysine and protein content, great variation was observed in the protein content as well as in the lysine level in the protein. Protein ranged from 10.4 percent to 20.0 percent and the lysine in the protein ranged from 2.14 percent to 3.80 percent. Environment has a considerable influence on protein and lysine content. Data from Sonora during the 1968–69 and 1969–70 seasons indicate that protein content increases and percent lysine in protein decreases with increases in the nitrogen level in the soil.

During the past year, some strains of triticales grown in different seasons and levels of nitrogen fertilization have been evaluated by Dr. F. Elliott of Michigan State University, using bio-assays employing the meadow vole. Several triticale lines have shown outstanding nutritional value of the protein in these tests.

Another development of interest was the recent discovery of a number of promising lines of Agrotriticum wheat-like derivatives. These are apparently derived from a translocation and characterized by large plump kernels of high grain test weight. Some of these lines also have high levels of grain protein.

CYTOPLASMIC STERILITY IN TRITICALE

DURING the past year *Triticum timopheevi* cytoplasmic sterility has been incorporated into triticale. The resultant crosses are completely sterile but upon backcrossing to triticale a few seeds are produced and the line can be maintained. It has been observed, in two preliminary test crosses, that a cytoplasmic sterile triticale pollinated with one of the better restorer hexaploid wheat lines gave a sur-

Visiting specialists get first-hand knowledge as one of the authors explains research being done in one of CIMMYT's triticale test plots.

prising degree of fertility. The validity and repeatability of these preliminary observations is now being explored. If verified, it could have important implications.

Triticale, unlike wheat, has large anthers which produce great quantities of pollen: in addition, the anthers are generally well exerted before dehiscing. These characteristics greatly expedite cross pollination and if an acceptable level of restoration can be found, it might become possible to produce a commercial triticale hybrid.

INTERNATIONAL COOPERATION

CIMMYT's contribution to international wheat research arose from the development of wheat varieties which could perform well in diverse areas of the world. This is particularly important in the semitropical and tropical areas which include many of the developing countries where food shortages exist. These varieties had to be day-length-sensitive, disease-resistant, lodging-resistant, and possess a plant structure which makes the most efficient use of the environment. Agronomic techniques and production practices had to be developed for the diverse environments existing in the developing countries in order that wheat could be produced competitively.

Young scientists had to be trained to demonstrate to farmers how the new techniques were applied in their own situations, using the new wheat varieties to increase production. Followup research had to be organized in the developing countries to forestall disastrous losses from diseases, insects, and other problems that may arise as a result of the newly created environment. Varieties of grain had to be developed which possessed a quality suited to the eating habits of the people of the various regions. To maintain this high level of production in a continuously changing world, a regular flow of the most advanced experimental lines and varieties is made available to collaborating scientists around the world.

This is the pattern the triticale program is hoping to follow. We started with the triticales at a very primitive stage of development. Before any real impact on food production is made with this crop, we must develop it sufficiently to become competitive in yield with the best wheat varieties. It must have better nutritional quality than wheat and have acceptance as human food. Agronomic improvement, utilizing basic and developmental research, is essential to bring about this transformation. To accomplish the task quickly we must have the cooperation of competent research scientists at other centers. We collaborate directly with several research institutions in our triticale program including the University of Manitoba.

POWER SOURCE OF THE FUTURE

Nuclear fusion—the same energy source that keeps the sun burning—may well be man's major power source in the next century. It has already been produced in the laboratory on an extremely minor scale. The big problem is to create and contain a temperature of 100 million degrees which will pull atoms apart.

One liter of a deuterium-tritium gas mixture used as the fuel could produce 10 percent of the energy requirement of the United States for 1 year. Some advantages of the system: no danger of a runaway chain reaction or accidental release of radioactivity, only minor waste problems, and abundant supplies of deuterium in sea water.

But some scientists say putting a man on the moon is child's play compared with the formidable challenge of developing usable fusion power.—*UIR Research Newsletter*, (Wis.) 6: 1, 1971.