THE DEVELOPMENT AND USE OF COMPOSITE VARIETIES BASED UPON THE MECHANICAL MIXING OF PHENOTYPICALLY SIMILAR LINES DEVELOPED THROUGH BACKCROSSING.

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Mexican wheat production has increased at a very rapid rate during the past ten years. Barring unforseen climatic disturbances such as widespread late frosts the 1956 crop production will satisfy national consumption. The national production has risen from 500,000 tons in 1950 to an estimated 1,100,000 tons forecast for 1956 (1). During this period the average national yield per hectare has risen from 750 kilos in 1950 to 1250 kilos per hectare forecast for the current crop.

The development and distribution of well-adapted, high-yielding rust-resistant varieties has been the principal catalyst in bringing about this revolution in wheat production. The new varieties have been the "crop insurance policy" which was necessary to motivate the other three principal changes, which have immensely contributed each in its own way toward solving Mexico's bread problem, namely: 1) the opening of large tracts of (new) irrigated land suitable for wheat culture, principally in the States of Sonora and Sinaloa; 2) a renewed interest and substancial increase in the area cultivated to this crop in the Bajío and Valleys of the Mesa Central, due to the spectacular increase in yields per acre in these "old lands" (wheat culture was uneconomical in this region until new methods, i.e., the use of fertilizers and improved varieties, were introduced in 1950); and 3) the establishment of wheat as a "temporal crop" (non-irrigated crop during the rainy season). Previously, with rust-susceptible criollo ("native") varieties, it was impossible to cultivate wheat at this season of the year because of losses from stem rust. Although the total area cultivated during the rainy season is still small the potential is large and can be expanded as the need for greater national production develops.

Currently wheat is grown largely as an irrigated crop during the winter dry season. The varieties are all of spring habit, but are grown from fall plantings which are made from November through January depending upon elevation and latitude. The crop is grown fron the California and Texas borders on the north, to the high Valleys of Chiapas near the Guatemala border on the south. It is grown from near sea level in Sonora and Sinaloa to an elevation of 3000 meters in some of the high Valleys of Central Mexico.

Ten years ago, with the exception of Sonora, wheat was grown with

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(1) The 1956 production reached 1,300,000 tons with an average national yield of 1370 kilos per hectare.

primitive cultural practices. Virtually all of the land-preparation, planting and harvesting operations were done by mule or horse drawn equipment or by hand. Land leveling, an operation which is essential if high yields are to be obtained under irrigation, was virtually unknown. Currently the majority of the land preparation for wheat throughout the Republic is done by tractor-drawn equipment, leveling is a common practice, and nearly all farmers use grain drills. There was virtually no chemical fertilizer used in Mexico in 1950. By 1956 there were very few farmers who did not use fertilizer on their wheat, excepting those who are planting on "new land". Within this same period large self-propelled combiners have largely replaced hand harvesting.

The principal diseases of wheat in Mexico are the rusts: stem, stripe and leaf, in that order of importance. Stem rust is by far the most dangerous since it can and sometimes does become epidemic at all elevations where wheat is grown. The climatic conditions are such that this organism persists in the repeating (uredinial) stage the year around at elevations of 1700 meters and above. This result in a rapid increase of inoculum whenever climatic conditions become optimum for the rust pathogen and unless resistant varieties are grown this can result in destructive epidemics. Stripe rust may become epidemic at elevations of 1700 meters and above in certain years on the irrigated winter crop, and it is a limiting factor every year during "temporal" plantings at elevations of 2200 meters and above. Leaf rust is present at all elevations in both the irrigated and "temporal crops", but up to the present time it has been the least important of the three rusts. Bunt was formerly an important disease, but a seed treatment campaign, combined with the multiplication and distribution of new varieties, has practically eliminated this problem.

Research and extension programs have played very important roles in increasing national wheat production. The breeding program has developed early-maturing, high-yielding, stem-rust-resistance varieties which have replaced the old criollo varieties on more than 95% of the area. These new varieties are much better adapted to improved agricultural practices than the criollo varieties. They will withstand heavy fertilization with a minimum of lodging, and moreover have glumes which are more resistant to shattering and therefore better adapted to combine harvesting. Soils research has resulted in the development of fertilizer recommendations for each of the major soil types. Research on cultural practices has resulted in improved methods of land preparation, rates and dates of planting, and in better irrigation practices. The combined result of this research and its enthusiastic acceptance by the farmers has made Mexico self-sufficient in wheat production.

The wheat production potential is adequate for Mexico's domestic needs for the next 15 to 20 years, if diseases can be kept under control. Sinaloa for example this year has 45,000 hectares of wheat planted where there was none four years ago. During 1957 the area will increase to 100,000 hectares, and if needed, it can be increased to 200,000 hectares within the next four years. The crop is also adapted in the lower Río Bravo (Río Grande) Valley and can be grown there commercially if necessary.

The potential hazards from stem rust have increased greatly during the past five years. The increased hazards have resulted from: 1) introducing wheat culture into more moist areas, such as Sinaloa, which is more favorable to the development of stem rust epidemics than areas where the crop was formerly grown; 2) a greater concentration (intensification) of commercial wheat production in certain geographic area (i.e., Sonora and Sinaloa) which automatically contributes to the dangers from rust epidemics when climatic conditions are favorable and when varieties are susceptible, and 3) the development of a much more favorable micro-climate for rust development within the grain fields as cultural practices have improved. Previous to the introduction of modern methods, wheat stands were sparse and plant development was very poor. Under such conditions the dew dried off the plants before 10 a.m. By contrast, wheat stands are rank and dense on farms using heavy fertilization and improved irrigation practices, Under these conditions the plants often remain wet with dew until mid-afternoon, thereby providing ideal ecological conditions for rust infection.

Despite the fact that the potential hazards from stem rust have increased greatly in the past six years, there have been no serious large scale commercial losses from rust. Even though there have been no serious losses during this period, on two occasions the crop was disconcertingly vulnerable to losses because of changes in the rust race population. The varieties Yaqui 48, Chapingo 48, Gabo, Kentana 48, and Lerma 50 were resistant to all of the prevalent stem rust races (17, 19, 38, 56 and 59) when they were released. The protection afforded against stem rust was, however, very short lived.

Stem rust race 15B, appeared in Mexico for the first time in March 1951, apparently resulting from inoculum blown in by northern air currents during the fall of 1950. It increased rapidly and became the most prevalent race on the Pacific Coastal Plain by 1952. This development made hazardous the cultivation of the varieties Yaqui 48 and Chapingo 48 (both carrying Hope type resistance), and Gabo (carrying T. turgidum type of resistance), since all three varieties were found to be very susceptible to this race. Similarly a group of closely related races 29, 48, 49 and 139 made their appearance and began to build up rapidly in Central Mexico during 1952 and 1953. This group of races proved to be highly pathogenic on the varieties Kentana 48 and Lerma 50. These two varieties carried Kenya 324 type of stem rust resistance, and therefore were resistant to race 15B.

Rapid multiplication and distribution of new varieties, combining the resistance to the old races and to 15B and to races 29, 48, 49 and 139, was carried out during 1952, 1953 and 1954. Through this program the varieties Chapingo 52, Chapingo 53, Lerma Rojo, Gabo 54, Sinaloa 53, Mayo 54 and Yaqui 53 were widely distributed and grown and have afforded protection to the commercial wheat crop in recent years. How long this resistance will remain effective no one can predict.

Even though the rapid multiplication and distribution of new varieties with resistance to the new races of stem rust provided the urgently needed protection from rust losses, there are many undesirable aspects associated with precipitous changes in varieties. Farmers are reluctant to rapidly shift their production from an old proven variety to an unknown new one. Their reluctance is based upon their familiarity with the old variety which permits them to exploit to the maximum its potential yielding ability. They know the best rates and dates of seeding of the old variety for their local conditions. They are familiar with the amount of fertilizer, the number and timing of irrigations which can be safely applied without unnecessary danger of lodging. When a new variety is introduced many of these considerations must again be worked out by the grower for his own local conditions before he is able to utilize a new variety in such a way as to approach its potential optimum productivity. Similarly the milling industry is often opposed to varietal changes, except when absolutely necessary, since it requires modifications in the blending of varieties going into their flours, and thereby complicated their industrial operations.

A third complication also sometimes occurs. When the appearance of new races threaten the commercial crop the breeder sometimes has no choice but to begin multiplication of a new variety which possesses the necessary resistance but may be inferior to the old varieties in one or more agronomic characteristics.

The sudden appearance of the new races of the rust organism thereby often leaves the plant breeder in a dilemma. On the one hand the growers and millers are reluctant to change varieties, and on the other hand failure to insist on such varietal changes, as soon as a suitable new variety is available, may result in severe economic losses throughout a large area.

The conventional backcross method of plant breeding comes closest to overcoming the dilemma. It provides, if properly carried out, new varieties which are phenotypically similar to the recurrent parent and therefore readily received by both farmer and miller. However, this method leaves much to be desired from the standpoint of the race population changes. Recognizing both the strong and weak points of the conventional backcross method the Oficina de Estudios Especiales in 1953 began a program to develop three composite or synthetic varieties of wheat. The three most important commercial varieties were chosen as recurrent parents for this program: Yaqui 50, with Newthatch type of stem rust resistance; Gabo, with T. turgidum resistance and Kentana 48, with Kenya 324 type of resistance. A group of more than 50 donor parents were chosen to cross with each of these commercial varieties. The donor parents were chosen on the basis of their reactions to stem rust in the International Wheat Rust Nurseries, and also on the basis of genetic and pathologic studies which had been carried out at many different institutions.

All segregating material from these crosses is handled by the backcross method. Backcrossing, whenever possible, is done on each succeeding F_1 generation. In all cases the F_1 plants are classified for resistance to one "tester race" in both the seedling and adult plant stage in order to identify the plants which are carrying the desired resistance. Tester race 15B is ideal for classifying Yaqui 50 and Gabo composite material, whereas tester race 29 is used for Kentana 48 material. The seedling tests of the F_1 material is carried on in the greenhouse, after which the seedlings are transplanted to the field into two rows, one containing the seedling resistant plants and a second row containing the susceptible seedlings.

Adult plant reactions are obtained from hypodermic inoculations made in the field on tagged culms of each plant. Inoculations are made with the tester race on culms in the early boot stage of development to obtain this reaction.

Backcrossing is continued as long as is necessary in order to recover lines which are phenotypically similar to the recurrent parent with respect to the principal agronomic characteristics: height, maturity, type of head, type of plant, and grain texture, color, size and milling and backing characteristics. The number of backcrosses necessary to obtain phenotypically similar lines depends on the similarity or dissimilarity of the two parents. In all cases, however, we are attempting to isolate the phenotypically desirable lines from populations derived from the minimum possible number of backcrosses, in most cases the third backcross. It is felt that by following this principle as far as possible, we may be able to retain in some cases additional disease resistance factors from the donor parent which will be valuable in controlling diseases of secondary importance such as leaf, and stripe rust.

Once the best lines have been isolated from the segregating populations of each cross they are planted in rod rows with the recurrent parent used as a check variety. These advanced generation lines are first classified for maturity, height of plant, and morphological spike and plant characteristics. At the same time the lines are planted in rod rows, seedlings of the same lines are classified in the greenhouse using separately at least two or three stem rust races representing the prevalent race groups. Adult plant reactions for the same stem rust tester races are obtained on the material being grown in rod rows by employing the hypodermic inoculation technique. Only lines which are phenotypically similar to the recurrent parent and which also posses an additional factor for stem rust resistance are harvested. Such lines are subsequently placed in yield tests and at the same time classified for their resistance in both the seedling and adult stages against all of the individual races of stem rust which are present in the area. In order to carry out this phase of the operation it will be necessary to retain viable inoculum of all of the stem rust races which have been collected in a given geographic area.

Ultimately the best lines (based on a joint consideration of yield, agronomic characteristics, stem rust reaction, and rust race populations), will be used to form the composite variety. The composite variety will be made up of a minimum of 8 to 10 phenotypically similar lines that differ genotypically for stem rust resistance. The lines that are included in the formation of the composite variety at any given time (period of years), will be governed by the relative prevalence of the different stem rust races and the type of resistance of each line. The make-up of the composite variety can be modified from time to time as dictated by the shift in the rust race population, by simply removing the line or lines that are permitting the increase of certain rust races and substituting other lines with different types of resistance. Viable seed of the best lines, or lines with each of the different types of rust resistance will be held in reserve, and can therefore be used to modify the composition of the composite variety as needed.

The effectiveness and the protection afforded by this composite variety, once it is grown on large commercial areas where the effect of the inblown inoculum produced on other types of resistance is reduced to a minimum, not only will depend upon the true resistance of the lines to the different races of the rust race population but will moreover depend in part upon the disease "escape mechanism", which functions more effectively in genotypically non-uniform populations. The increase in the amount of inoculum is delayed, especially in the first few generations, when rust begins to increase in a genotypically diversified population, and this delay theoretically will often permit even the susceptible lines in the composite variety to mature their grain before serious damage results. Under the conditions described above it is highly improbable that a line which is susceptible to one race in the rust population will be damaged severely, since it does not constitute more than 10 to 12-1/2 per cent of the composite population. This phenomenon is a principle which was used knowingly, by many early agricultural societies in both hemispheres to reduce crop losses from diseases, insects and drought. The present proposed system of developing composite varieties through a modification of the backcross system will simply remove the objections which are inherent in the use of mixture of phenotypes as was common in the varieties of early agricultural societies.

The use of composite varieties as described above will probably provide at least partial protection for the farmer whenever new races become prevalent and up until the time the varietal composition can be modified, since it is quite improbable that all genotypes of the composite will be completely susceptible to such a new race. As soon as a new race appears all of the lines of the variety and all of the lines held in reserve must be classified for their resistance to the new race. The composite variety can then be reformed with lines which will give maximum protection against the newly modified race population.

Should a "super-race" of rust appear which is capable of attacking all sources of resistance obviously this method like all others is doomed, but this seems highly improbable. If a "super-race" does not appear the proposed system provides the maximum flexibility that can be incorporated into any system of breeding of self pollinated crops. It will obviously find its greatest application in those crops where airborne epidemic diseases are of paramount importance, and where the race populations can change with fantastic rapidity and produce disastrous effects. The degree of refinement of the system will vary with the crop and the stage of evolution of the agricultural society in which it is employed. In countries such as the United States and Canada where standardization of wheat quality is a paramount consideration in the breeding programs the method would certainly require a greater number of back-crosses to develop the lines with the required characteristics than is currently necessary under conditions in Mexico.

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THE USE OF INDUCED MUTATIONS IN BREEDING WHEAT

FOR RESISTANCE TO RUST.

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The development of improved disease-resistant varieties has constituted for many years a major part of cereal breeding programs in North America. Especially during the last two decades, plant breeders have been harassed by the appearance and rapid spread of new diseases or new forms of old diseases. To meet this challenge, breeders have found it necessary to expend their efforts almost solely in the transferring of new resistance genes to locally adapted varieties. At best, they have found it difficult to keep ahead of the advance of the pathogens.

With wheat rust, the picture seems almost at the stage where a new race may appear, spread rapidly and cause its damage, and then be replaced in importance by a different form before resistance can be rallied in new wheat varieties. This hasn't happened yet, but it could happen! Improved methods now applied by wheat breeders show that they have recognized this danger. It is now possible through better State and International cooperation for breeders of spring wheat to increase their desirable selections by growing two crops each year. In addition, with controlled growth rooms now more generally used, it is possible to carry on an accelerated backcrossing program that greatly reduces the time required for the transfer of desired new genes into old adapted varieties. However, when a new disease problem appears, plant breeders and plant pathologists must still search through an enormous collection of varieties and introductions to find resistance sources with which to work. This has never failed to produce results - but it does take time when time may be very expensive to the farmer.

If it were possible for the plant breeder to induce the desired resistance factors in his own locally adapted material, a great deal of that valuable time might be saved. Moreover, the breeder could devote a larger share of his program to improving the yield, quality and other characteristics of his crop varieties.