MEXICAN WHEAT PRODUCTION AND ITS ROLE IN THE EPIDEMIOLOGY OF STEM RUST IN NORTH AMERICA

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SUMMARY

Despite the set-backs which have been caused by changes in races, a great deal of progress has been made since the wheat improvement program of the Oficina de Estudios Especiales was established in 1943. Yields per acre are increasing, new areas suitable to economical wheat culture have been established, and the 1953 harvest is the largest in Mexican history. Much of the most important basic agronomic information has been obtained and much of it is being successfully put into commercial application. The ever-changing variable, the rust population, is one of the limiting factors in wheat production that has not been solved permanently. Nor is it likely to be solved in the future, for the variability of this type of pathogen is extremely great and will continue to require research to meet the constantly changing race composition. More flexibility in approach than that which is possible by conventional breeding methods is necessary and is being investigated. This truly international problem is not restricted to stem rust, for in Mexico, at elevations above 7500 ft., the stripe rust problem is also imposing. In some other parts of the hemisphere, leaf rust is more important than either of these other 2 rusts of wheat.

In considering the international wheat stem rust problem in North America, most farmers must reorient their thinking with respect to the value of severe winters and high summer temperature in reducing rust inoculum. Both of these factors often contribute to a bountiful wheat crop in the forthcoming year, and consequently are a blessing in disguise.

American farmers have obtained great benefits from the use of stem rust-resistant varieties during the past 20 years. The success of these varieties has been due at least in part to the "escape mechanism" of disease control. The use of this mechanism will be even more important to the farmers of the northern Great Plains in the next few years until the newer varieties with resistance to race 15B and others become generally available. In a mountainous country such as Mexico, winter temperatures are not sufficiently low nor the summer temperatures sufficiently high to destroy urediospores of the stem rust fungus. Therefore, over the centuries the farmer has become fully aware of the value of the "escape mechanism" as the surest means of obtaining a successful crop. He has learned to manipulate dates of planting and to use irrigation water properly to minimize the losses from rust. In considering the role of the Mexican wheat crop in the epidemiology of the stem rust organism (*Puccinia graminis tritici*) in North America, nearly equal attention must be given to the Mexican barley crop

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which is also a constant reservoir of inoculum.

CONDITIONS UNDER WHICH WHEAT IS GROWN IN MEXICO.—Wheat is grown commercially from 32° along northern border to 16° in the high valleys of Chiapas in the South. Within this zone wheat is grown from a few feet above sea level in Sonora to an elevation of 10,000 ft. in some of the high valleys of South Central Mexico. More than 95 per cent of the wheat crop is grown either under irrigation or on reserve soil moisture during the winter months. Plantings are generally made during the months of October, November, and December, and harvesting is done during April, May, June, and July, depending on the elevation. Planting dates must be manipulated so that the wheat does not head until the danger from frosts has passed. All varieties are of spring habit (7, 2, 14).

The relatively small acreage devoted to the summer culture of wheat is planted in May and June and harvested in October and November (8). Virtually all the barley is planted and harvested during this same summer period. The summer plantings of both wheat and barley are not irrigated and the dates of planting coincide with the beginning of the summer rainy season. Harvesting is done at the beginning of the winter dry season.

SMALL GRAIN PRODUCTION REGIONS IN MEXICO.—The areas devoted to wheat and barley production can be divided into 4 principal regions on the basis of production and breeding problems.

Region #1—The Pacific coastal plain (15–300 ft. elevation).—This region comprises the irrigated coastal plain of Sonora and, more recently, it has extended southward into Sinaloa. Irrigation water is obtained from large dams and in some cases from deep wells. The cultivated lands in this region are relatively new, none having been cultivated more than 40 years. Large areas of new land are being opened to culture as new irrigation projects are completed. Yields on new lands are high, but diminish rapidly after 5 years in cultivation unless fertilized properly. Lodging, shattering, and control of stem rust are important considerations in this region. Wheat culture has extended rapidly southward into Sinaloa in the past 2 years. This western coastal region at present produces 50 per cent of the wheat crop of the Republic. All the land preparation, planting, and harvesting are done by modern machinery. Cotton and rice are the principal summer crops in this region.

Region #2—La Laguna (3000 ft. elevation).—This region comprises a very specialized region in Northern Mexico. Soils are for the most part highly alkaline and of low fertility. The atmosphere is extremely dry and rusts are not a serious problem. Irrigation water is obtained from dams and deep wells. The planting and harvesting are done largely by machinery. Cotton is the principal summer crop in this area.

Region #3—El Bajio (5000–6500 ft. elevation).—This region comprises the black soils of Central Mexico. They have been cultivated continuously since colonial times and are now of extremely low productivity unless properly fertilized. Irrigation is provided from dams and deep wells. Stem rust sometimes causes severe losses. Mechanization within this region has increased greatly within the past 5 years, but much of the area is still cultivated by primitive methods. Corn is the main summer crop.

Region #4—The mountain valleys (6500–9500 ft. elevation).—This region is made up of a heterogeneous group of scattered high mountain valleys, extending from Northern to Southern Mexico. Soils are of low fertility. Irrigation water is provided by small dams, deep wells, and in some cases wheat is grown on reserve soil moisture. Stem rust may become destructive in some years throughout this entire area. Stripe rust is also a problem. Virtually all production within this region is carried on by primitive methods.

It is within this region that virtually all the barley and the summer wheat are grown. Corn is the most important ~~additional~~ summer crop in this region.

RUST EPIDEMIOLOGICAL CLASSIFICATION.—On the basis of consideration of the epidemiology of the stem rust organism, Mexico can be divided into 2 zones: 1) the Pacific Coastal Zone and 2) the Mountain Zone.

The Pacific coastal zone (10–500 ft. elevation).—Summer temperatures are extremely high in this area and summer rains are unpredictable. The mode of over-summering of stem rust urediospores in this region is unknown. Although occasional volunteer wheat plants emerge and develop poorly, stem rust has not been found on these volunteer plants. Perhaps infected volunteer plants survive in protected areas along irrigation canals, or perhaps the rust survives in the uredial stage on grasses or barley in the mountains, and the spores are blown back down to the coast in the fall. The first infection of stem rust on wheat generally is not found on the west coast until January.

Mountain zone.—At elevations of 4000 ft. and above, the stem rust organism frequently survives in the uredial stage throughout the year. Rusted volunteer wheat plants are common in the corn and bean fields during the summer. Barley and wheat are cultivated during the rainy season in many valleys above 7000 ft. and generally these become infected with rust. Several species of grasses, especially wild barley, have been found infected with stem rust. Clumps of *Hordeum jubatum* have been observed in the valley of Mexico where the uredial stage of stem rust has survived continuously over a period of 3 years. Similarly, at Chapingo the uredial stage has been observed to survive on 3 generations of volunteer wheat plants over a period of 18 months.

Throughout this zone the amount of inoculum of stem rust is reduced greatly at the onset of the dry season in October and November as a result of the dryness of the atmosphere and by repeated light frosts.

RACES OF PUCCINIA GRAMINIS TRITICI IN MEXICO.—The early investigations of Stakman and coworkers established that the races of the stem rust pathogen prevalent in Northern Mexico generally were the same races that were prevalent during a similar period in the Great Plains of the United States and Canada. These early studies also indicated that it was several years after a race of rust became established in Northern Mexico before it appeared in South Central Mexico, indicating that some isolating factor influenced the interchange of inoculum between these 2 regions.

When the wheat improvement program of the Oficina de Estudios Especiales was begun in 1943, races 17, 19, 38, 56, and 59 were prevalent in 1 or more geographic areas of Mexico (15). Therefore, the first step was to obtain suitable varieties with resistance to these races.

IMPROVEMENT PROGRAM OF THE OFICINA DE ESTUDIOS ESPECIALES.—Prior to 1943, virtually all the area planted to wheat was seeded with "native" varieties of unknown origin. The only varieties of known origin were Mentana, which was introduced from Italy in the late 1920's, and a small acreage in Sonora which was planted with Ramona and Baart from California. Virtually all the "native" varieties, with the exception of Aguilera, Candeal, and Barrigon, were badly mixed, and most farmers' fields were mixtures of many different types. It was common to encounter 10–20 morphologically different types of wheats, belonging to 3 different species, in a single field. These types differed greatly in maturity, height, resistance to lodging, shattering, and in grain texture, resulting in complicated harvesting, milling, and baking procedures (2, 7).

From the time the program was initiated, the problem was attacked from 3 different points of view, namely: 1) improvement of cultural practices, 2) studies to determine proper fertilization and rotation practices, and 3) a breeding program to develop disease resistant varieties for each region, suited to improved cultural and fertilizer practices.

The breeding program from the beginning was based on 3 different approaches: 1) selection in "native" varieties, 2) introduction and reselection in materials from other countries, and 3) a crossing program, wherein the best "native" types were crossed with the best introductions (2, 14).

IMPROVEMENT THROUGH SELECTION.—Approximately 8500 individual head selections were made in farmers' fields in different parts of the Republic in 1944 and 1945. Within this group more than 5000 selections were of bread wheat types. All but 2 of these proved to be highly susceptible to stem rust in subsequent tests. The 2 lines with considerable resistance were extremely long-strawed and susceptible to lodging and, consequently, were not used as commercial varieties. However, they were used extensively in the breeding program. Of the remaining 3500 selections which were largely representatives of the species *Triticum durum* and *T. turgidum* ("hump-backs"), many were found to be resistant to the races of stem rust then present. However, Mexico's need was one of increasing the bread wheat acreage and reducing the acreage cultivated to "hump-backs" and durum wheats. Therefore, none of these latter wheats was multiplied for commercial usage. In 1944 probably 50 per cent of the entire area cultivated to wheat in the Republic was of the "hump-back", and, to a lesser extent, durum types. The large area cultivated to "hump-backs" was the result of the disastrous stem rust epidemics on bread wheats during 1938 and 1939. The 2 "hump-back" varieties were highly resistant to the common races of the stem rust pathogen that were then prevalent.

During the first 3 years of the program particular attention was focused on the introduced materials. From this material 4 varieties were developed by reselection. Two of these, Supremo 211 and Frontera, came from reselections made in hybrid material received from E. S. McFadden of Texas, and the remaining 2 were reselections from Kenya wheats. These varieties were distributed commercially in 1948 and served a useful purpose through 1951 and 1952 by which time they were largely replaced by the varieties Yaqui 48, Chapingo 48, and Kentana 48, which were developed from the breeding program begun in April of 1945. The former 2 varieties were derived from a cross of Marroqui (originally a Moroccan variety) × Newthatch, and the latter from a cross of Kenya × Mentana. Lerma 50, which was derived from the second backcross of Kentana to Mentana, was released in 1951, and Gabo, a variety "screened" from the U. S. Department of Agriculture world wheat collection, was first increased in 1951.

Since the initiation of the breeding program in 1945, 2 field generations of all crosses have been grown each year. The winter planting in November and December which simulates the planting of the main commercial crop is made at 7 regional nurseries varying in elevation from 20–8500 ft. in widely dispersed geographic areas of the Republic. All lines selected from the winter nurseries are regrown in 1 of the 4 summer nurseries which are planted during May and June. Selections in the summer nurseries are made primarily on the basis of resistance to stem and stripe rusts. Severe epidemics have developed in the summer nurseries since the program was initiated, thereby greatly facilitating the selection of lines resistant to stem rust. During the first 6 years of the program all selections for disease resistance were made on the basis of field reaction alone. For the past 2 years satisfactory greenhouse facilities have become available and are used for checking the seedling and adult plant reaction of all lines which enter regional rod-row trials.

Special effort was made to incorporate a broad base of resistance to stem rust. Large numbers of crosses have been made and processed. All the material for the first 6 years was handled using the Pedigree method. Since 1951 major emphasis has been placed on further improvement through use of the backcross

TABLE 1.—*Shift in varieties grown in El Bajio (#3) and mountain valley (#4) regions from 1948 to 1953*

Variety	Percentage of Commercial Average		
	1948	1950	1953
Native Varieties			
1. "Barrigon" ("Hump-back")	30	30	15
2. Old Bread-Wheat Varieties (Rojo, Candeal, Queretaro, Mentana, etc.)	60	30	10
Improved Bread-Wheat Varieties			
1. Supremo 211	5	30	5
2. Kenya	4.5	5	0
3. Kentana	0.5	5	50
4. Lerma	0	Trace	20

method since the improved varieties Yaqui, Gabo, Lerma and Kentana possess most of the desired characteristics.

RESULTS FROM BREEDING PROGRAM.—The rapid acceptance of the first 4 varieties of wheat derived from the breeding program, and of Gabo, which was screened from the U.S.D.A. World Wheat collection, is indicated in Tables 1 and 2 for the Bajio and High Valley and Pacific coastal regions, the 2 most important wheat producing areas in the country. It is estimated that the new varieties which were in semi-commercial increase in 1948, were planted on more than 70 per cent of the area cultivated to wheat in 1953. Once the new varieties were released they were multiplied twice each year, thereby resulting in large volumes of seed being made available to the farmers in a short time. The rapid acceptance of these varieties is the result of a combination of characteristics. They were more resistant to the prevalent races of stem rust than the native varieties which they replaced except in the case of the hump-back "Barrigon". Moreover, these newer varieties were better adapted to an improved agriculture. Heavy fertilization could be practiced without danger of lodging, whereas all the native varieties lodge badly when fertilized heavily. The new varieties were well adapted to combine harvesting which has become common in many areas of the Republic within the past few years. The newer varieties were from 10 to 18 days earlier than the varieties they replaced, thereby making it possible to grow a larger acreage of wheat with a given quantity of water for irrigation. The milling and baking properties of the new varieties were superior to the former varieties. The sum total of these advantages has resulted in much higher yields per acre to farmers who combine the use of the improved varieties with improved land preparation, proper fertilization, and proper use of irrigation water. The best farmers in the Bajio area, on land which has been farmed continuously for 350 to 400 years, are now harvesting 45 to 60 bu. per acre on the same land where they were harvesting 8 to 15 bu. per acre with old varieties and old methods only 5 years ago. The outstanding example of progress in increasing wheat production on a given tract of land is that of a Sonora farmer who this year harvested 5600 bu. of Gabo on the same 80-acre tract where he harvested 640 bu. of Aguilera 3 years ago. This phenomenal increase in yield is not to be expected on all farms. However, by combining proper cultural, fertilization, and irrigation practices with the use of the proper improved variety, it should be possible to double the national average yield within the next 5 years, providing stem rust can be kept under control. The newly organized extension service, backed by sufficient agricultural credit, can put the improved practices into operation on the *ejidal* farms.

TABLE 2.—*Shift in varieties in Pacific coastal plain (#1) region from 1948 to 1953*

Variety	Percentage of Commercial Average		
	1948	1950	1953
Native Varieties			
1. Barrigon ("Hump-back")	75	60	15
2. Old Bread-Wheat Varieties (Aguilera, Candeal, Baart, Ramona, etc.)	25	10	Trace
Improved Bread-Wheat Varieties			
1. Kenya	0	5	Trace
2. Yaqui "48"	Trace	20	65
3. Kentana "48"	0	5	10
4. Lerma "50"	0	Trace	4
5. Gabo	0	Trace	4
6. Others	----	----	2

With the development of early-maturing stem and stripe rust-resistant varieties and with the use of chemical weedkillers, it has become economically feasible for the first time to grow wheat during the summer rainy season in the high valleys of South Central Mexico.

SHIFT IN RACES OF STEM RUST.—Prior to 1951, races 17, 19, 38, 56 and 59 of *Puccinia graminis tritici* were prevalent in Mexico. The 5 improved varieties described earlier are resistant or moderately resistant to all these races. Race 15B became present in the Northern Great Plains of the United States and Canada in the summer of 1950. Prior to that time it had never been found in Mexico. By April and May of 1951 it began to appear in widely different geographic areas of the Republic, from Sonora on the Pacific coastal plain to the states of Puebla, Mexico, Michoacan and Jalisco in South Central Mexico. By September of 1951 this race constituted 70 per cent of the isolates in Central Mexico. Of the new varieties, Yaqui, Chapingo, and Gabo proved to be susceptible to race 15B, whereas Kentana and Lerma, with Kenya type of resistance, were found to be resistant. The screening effect of these latter 2 varieties is clearly indicated by Fig. 1, which shows that the prevalence of race 15B in North and South Central Mexico rapidly decreased during 1952 and 1953 as the acreage of Kentana and Lerma increased. On the Pacific coast where Yaqui, susceptible to 15B,

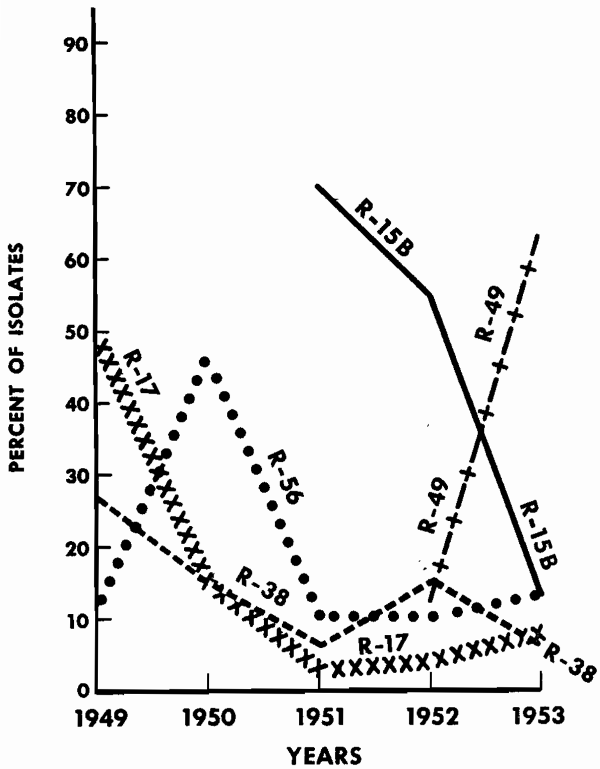

FIG. 1. Relative prevalence of physiologic races of *Puccinia graminis tritici* in the Bajio and High Valley regions (#3 and 4) from 1949 to 1953. (Note effect of varieties on prevalence of races 15B and 49 in Fig. 1 and Fig. 2.)

comprises the major acreage, race 15B constitutes more than 60 per cent of the isolates (Fig. 2).

It is of interest that race 15B has not yet reached the wheat-growing areas of Guatemala. Supremo grown there is extremely susceptible to race 15B but has developed no rust through 1952.

Almost concurrently with the rapid decrease in race 15B in Central Mexico, where a large percentage of the area is Kentana and Lerma, there has been a very rapid build-up of 2 new races, namely 49 and 139. The former race was common in the United States and Northen Mexico in the 1930's and decreased or practically disappeared by 1943 as the Hope type of resistance became common in the United States and Canadian wheat belts. It was not found in South Central Mexico prior to 1953.

Race 139, which from the breeders' standpoint is very similar to race 49, had been isolated several times prior to 1950 but had never shown signs of becoming prevalent. It is now known that these 2 closely related races began to increase on late planted fields of Kenya 324 in the Sierra de Arteaga near Saltillo, Coahuila, in the spring and summer of 1950. Since no commercial damage was caused, the outbreak was unreported. The race increased last summer in the same area and by July had killed several thousand acres of Kenya 324. During September of 1952 many infection centers of race 49 began to appear in South Central Mexico on Lerma and Kentana, which carry Kenya type of resistance to race 15B and are susceptible to race 49. The present indications are that this race will constitute more than 90 per cent of the isolates in the states of Hidalgo, Mexico, and Puebla this summer. The varieties Yaqui and Gabo, which are susceptible to race 15B, are highly resistant to races 49 and 139 (6, 9, 10).

PROBLEM FOR THE IMMEDIATE FUTURE.—As a result of the 2 sudden shifts in the stem rust population within the past 3 years, none of the 5 improved commercial varieties possesses resistance to all widespread races. Once again we must adhere strictly to the escape mechansim of proper dates of planting and proper manipulation of irrigation schedules to minimize the hazard of stem rust.

At the present we are beginning to increase 3 new varieties which apparently carry combined resistance to races 15B, 49, 139 and to the 5 formerly common races 17, 38, 56, 19 and 59 (6, 10). The question is how long will these varieties remain resistant? Will they remain resistant over a period of 15 years

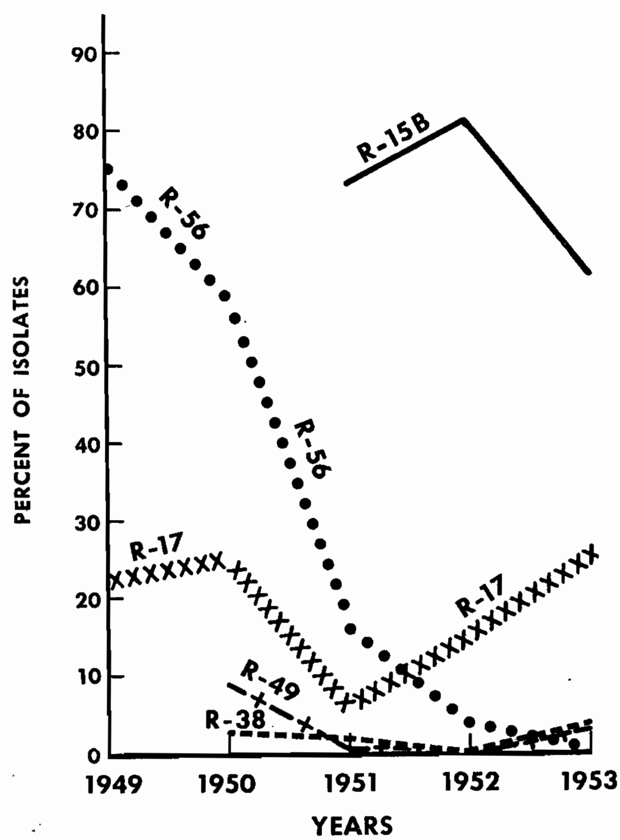

FIG. 2. Relative prevalence of physiologic races of *Puccinia graminis tritici* in the Pacific Coastal Plain from 1949-1953.

as did Thatcher in the United States and Canada and as did Barrigon, the "hump-back" variety of the coastal plain of Sonora, or will they become susceptible through a shift in races within 1 to 5 years as did Lee and Kentana? No one can safely predict the answer to these questions. Nevertheless several points have become increasingly clear within the past few years with respect to the epidemiology and breeding problems, namely:

1) In the autumn the rapid, long-range dissemination of spores of new races from Northern United States and Canada to South Central Mexico can and does take place in 1 step, not necessarily by several, and in the spring the northward movement of spores occurs in a similar manner.
2) There seems to be no barrier to the exchange of spores from Northern Mexico to South Central Mexico.
3) The value of the escape mechansims as an indirect means of control of stem rust and of extending the period of usefulness of a resistant variety in the Great Plains of North America cannot be fully appreciated until one has had an opportunity to observe the potentially rapid increase of inoculum under conditions where the parasite survives perpetually in the uredial stage.
4) Improved agricultural practices often increase the rust hazard by changing the micro-climate within the grain field. Fields grown under old methods, poor seed bed preparation, poor stands, no fertilization, and yielding 8 bu. per acre generally, have only 50 heads per square meter, whereas a field heavily fertilized, with a good stand of plants yielding 70 bu. per acre on the same soil type, will have from 500 to 530 heads per square meter. In the low yielding plot the dew will dry off the plants by 9:30 A.M., whereas in the high yielding plot the plants will still be wet at 1:30 P.M.
5) The hazard of stem rust in Mexico may increase as the culture of wheat spreads farther south on the Pacific coastal plain. With the establishment of the new "Falcon" International Irrigation Project on the lower Rio Grande, wheat will undoubtedly become one of the important winter crops on the Mexican side of the river. This may result in the inoculum moving into the Great Plains somewhat earlier than it does at present.
6) There is an urgent need for modification of the present stem rust differentials, so that "gene testers" and varieties which are used currently in breeding programs will be incorporated into the differentials used in the identification of the rust population. This will bring about a closer and more direct coordination between rust population studies and breeding programs.
7) There is need for a new approach to the breeding problem. The use of "flexible composite synthetic varieties," which are made up of phenotypically similar lines that are genotypically different for resistance, is proposed and being developed by our organization. The lines employed in such a variety would be bulit up by the conventional backcross method but would be mechanically mixed to form the composite variety. Then the composition of the variety can be modified rapidly as the rust population shifts (3).
8) There is urgent need for extensive research in an attempt to develop a satisfactory chemical control for rust. This control could be used in any emergency when epidemics are imminent and when shifts in the rust populations temporarily render all or most varieties susceptible. Very little effort and research have been directed toward this end.
9) The cooperative International Nurseries which have been in operation the past 3 years have developed a wealth of valuable information which is basic to all breeding programs. It is certainly one of the outstanding achievements in international technical cooperative efforts (1, 4, 5, 11, 12, 13).

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