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EXOTIC GERM PLASM FOR IMPROVEMENT OF CORN BELT MAIZE

by DR. E. J. WELLHAUSEN[1]

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EXOTIC GERM PLASM FOR IMPROVEMENT OF CORN BELT MAIZE

by DR. E. J. WELLHAUSEN[1]

DURING THE LAST 22 YEARS, in one way or another I have been associated with the collection, classification, evaluation, and utilization of the vast range of germ plasm that exists in the species *Zea mays* in Latin America. To date, over 300 different races of maize have been described (4). Seed of varieties most typical of each of these races is being stored in the four maize seed banks located in Mexico, Colombia, Brazil and the United States (Fort Collins), respectively. This collection of seed is a gold mine for the further improvement of maize around the world.

The single most important factor in the evolution of this variation has been hybridization. Some very outstanding varieties have developed from natural selection with the conscious and/or unconscious help of man, in populations resulting from the chance inter-hybridization of different races. This sort of thing is still occurring today. In Jalisco, Mexico's number one corn producing state, farmers have developed some outstanding varieties from the natural inter-hybridization between the prevailing indigenous Tabloncillo types and the hybrids developed from the race Celaya which were introduced about 15 years ago. In the Jala valley of Nayarit, the famous long eared race, Jala, is rapidly being replaced by varieties which the farmers have developed from the natural intercrossing between Jala and the Tuxpeño race introduced in 1952.

E. J. WELLHAUSEN

Some of the outstanding indigenous varieties of Mexico such as Chalqueño, Celaya and Tuxpeño are readily capable of producing at the rate of over 100 bushels per acre under good fertility and moisture conditions. If this is what man and nature have produced in a more or less haphazard way through chance inter-hybridization of different varieties and races, what can the modern geneticist do with his present knowledge of genetics and gene action, and with over 300 different races at his disposal? So far,

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no variety has developed from the sampling of the entire range of variation existing in maize. What are the possibilities of developing some new races, much more productive than anything man has created to date, from a more complete and systematic exploitation of the germ plasm reserves as yet largely untouched? This is what I would like to talk about during the brief time allotted to me on the program today.

HETEROSIS IN INTER- VS. INTRA-RACIAL CROSSES

In recent years we have devoted considerable effort to the identification and utilization of elite germ plasm complexes. We have made and tested many intra- and inter-racial crosses in collaboration with our many colleagues in maize improvement throughout Latin America. The data presented in Table 1 are indicative of the kind of results being obtained. In this table are listed the inter-racial crosses which in F_1 yielded over 130 bushels per acre in the Bajio region of Central Mexico. They represent the 18 highest yielding crosses out of a total of 300 involving all possible crosses among the 25 races in Mexico described by Wellhausen *et al.* (4a). The test was planted in April at 1,800 m elevation near Celaya, Guanajuato,

TABLE 1

Performance of outstanding inter-racial crosses in test made near Celaya, Guanajuato.[a]

Cross	Yield in kg/ha			Yield of F_1 in % of		No. Ears/100 Plants		
	P_1	P_2	F_1	$\frac{P_1+P_2}{2}$	High Parent	P_1	P_2	F_1
Pepitilla x Chalqueño	6,440	4,530	9,840	179	153	168	103	175
Pepitilla x Tuxpeño	6,440	5,340	9,430	160	146	168	111	167
Pepitilla x Maiz Dulce	6,440	5,940	8,800	142	137	168	141	188
Pepitilla x Cacahuazintle	6,440	1,910	8,300	199	129	168	92	159
Pepitilla x Nal-Tel	6,440	1,850	8,240	199	128	168	207	266
Pepitilla x H.Ocho	6,440	4,630	8,100	146	126	168	181	175
Maiz Dulce x Comiteco	5,940	5,490	8,940	156	150	141	103	147
Maiz Dulce x Olotillo	5,940	3,560	8,820	186	148	141	131	201
Maiz Dulce x Tehua	5,940	940	8,700	253	146	141	74	288
Maiz Dulce x H.Ocho	5,940	4,630	8,490	161	143	141	181	217
Maiz Dulce x Celaya	5,940	8,060	8,320	119	103	141	149	201
Maiz Dulce x Jala	5,940	5,950	8,260	139	139	141	106	165
Maiz Dulce x Tepecintle	5,940	4,729	8,070	151	136	141	119	190
Comiteco x Celaya	5,940	8,060	9,060	134	112	103	149	113
Comiteco x Chapalote	5,940	3,420	8,340	187	152	103	193	165
Comiteco x Con.Norteño	5,940	6,410	8,110	136	126	103	154	128
Hybrid H352			7,260					173

[a] Data taken from thesis by Mario Castro G. (1).

in an area where the race Celaya predominates. The test plot was fertilized with nitrogen and phosphorus, applied at the rate of 120 kilos of N and 80 kilos of P_2O_5 per acre, respectively. Moisture was supplied through irrigation as needed, and insects were controlled with appropriate insecticides. Interesting observations to be made from the data in Table 1 are summarized as follows:

1. All crosses listed involve parents of very diverse origin.

2. Yields of all crosses are significantly higher than the hybrid H352 made from inbred lines out of the race Celaya.

3. The average yield of the crosses is 138 bushels per acre and 19 per cent higher than the hybrid H352.

4. Heterosis, expressed in terms of yield of F_1 in per cent of average yield of the two parents (midparent) ranged from 119 per cent to 253 per cent with an average for the 18 crosses of 164 per cent.

5. The highest degree of heterosis expressed in terms of yield of F_1 in per cent of midparent was exhibited by the cross Maiz Dulce x Tehua. Tehua is a very tall, high eared, thick stemmed, late maturing race, prevalent in the high altitude area of Chiapas, near the Guatemalan border. It is almost completely unadapted to the area in which the tests were made, yielding very little in this region.

6. Yield of F_1 in percent of the highest yielding of the two parents of a particular cross varied from 103 per cent to 153 per cent.

7. Certain races appeared more frequently in the high yielding crosses than others. The three races which appeared most frequently were Pepitilla, Maiz Dulce and Comiteco. With few exceptions, each combined well with a different set of races.

8. Three of the four races classified by Wellhausen, *et al.* (4a) as pre-Colombian Exotic—namely, Maiz Dulce, Cacahuazintle and Harinoso de Ocho, and thought to have been introduced from South America in pre-Colombian times—are represented among the 18 highest yielding crosses. The fourth of the pre-Colombian Exotic races, Oloton, is postulated as one of the parents of Comiteco. The race Pepitilla, although not so indicated by Wellhausen *et al.*, is now thought to have been influenced in its evolution by one of the Guarani races described by Brieger *et al.* (4e).

9. The ancient indigenous, early maturing, low yielding races Nal-Tel and Chapalote are also represented among the races involved in the highest yielding crosses. It is evident, however, that a combination of two high yielding races such as Pepitilla x Chalqueño yielded significantly more than a combination of high by low such as Pepitilla x Nal-Tel.

10. Number of ears per 100 plants in each of the crosses ranged from 113 to 288, with an average for all 18 crosses listed, of 184. The number of ears per 100 plants in the hybrid was 173.

11. Crosses containing Maiz Dulce tended to produce more ears per 100 plants than the others listed.

12. The highest degree of heterosis in number of ears per 100 plants was exhibited by the cross Maiz Dulce x Tehua.

In consideration of the way certain high yielding varieties have evolved in the past, it is conceivable that a variety much higher in yield than the race Celaya, which predominates in the Bajio area where the test was made, could be developed through

a gradual concentration of the additive variance in the advanced generation progeny of a mixture of certain of these inter-racial crosses. It is quite likely that an open pollinated variety could be developed from a mixture of this kind which would yield as much or more than the best hybrid that could be developed from the race Celaya. However, in view of the extreme diversity involved, this approach might not be the most immediately practical one from the standpoint of raising the genetic yield level in the area where the race Celaya predominates and still be within the range of types which the farmers will grow.

YIELD IMPROVEMENT THROUGH RACIAL BLENDS AND MASS SELECTION

In an attempt to determine what it takes to develop an acceptable product out of a mixture of very unrelated germ plasm complexes, we have combined some of the racial inter-crosses listed in Table 1 and are proceeding with the process of "mixing" the various materials involved in the advanced generation progenies. After five generations of mixing, we plan to begin concentrating the additive yield variance through a simple recurrent mass selection technique. In the meantime we have undertaken another procedure which we believe will yield something more immediately useful.

In this second procedure we topcrossed the best varieties of the race Tuxpeño, Celaya and Comiteco on a variety of Celaya identified as Gto. 61. In a test of these top crosses, over 200 in all, in two localities of the Bajio region, the best ones were identified. The data presented in Table 2 show the kind of results we obtained. The relative performance of two of the highest yielding crosses within each of the three types of crosses in the test—namely, Celaya x Celaya, Celaya x Tuxpeño and Celaya x Comiteco—is shown in this table. It is very evident from the data presented that: (1) crosses of varieties from different races exhibit greater heterosis than crosses of varieties of the same race; and (2) crosses of unrelated races produce a higher degree

TABLE 2
Yields of inter- vs. intra-racial crosses.

Crosses	Yield kg/ha		Av. Yield in % of:	
	F_1	Av.[a]	Cel. x Cel.	Celaya
Celaya (G61) x Comiteco (CG60)	8,216			
Celaya (G61) x Comiteco (CG56)	7,576	7,896	118	140
Celaya (G61) x Tuxpeño (SLP11)	7,500			
Celaya (G61) x Tuxpeño (VG15)	7,291	7,340	111	130
Celaya (G61) x Celaya (G65)	6,745			
Celaya (G61) x Celaya (Q42)	6,578	6,661	100	118
Celaya (Av. of 3 Varieties)		5,643 (81 Bu/A)	84	100

[a] Average of two crosses between the same races.

of heterosis than crosses of related races. The race Celaya is much more closely related to Tuxpeño than Comiteco. As a matter of fact, Celaya has an ancestry very similar to that of Tuxpeño. They are very much alike in their ear and grain characteristics.

Seed from the better top-crosses was combined to form a population containing approximately two parts of Celaya germ plasm to one part of Tuxpeño and Comiteco. Mass selection was immediately started in the F_2' generation of this Celaya-Exotic composite with a selection intensity of about 25 per cent. In the second cycle of mass selection the selection intensity was reduced to about 15 per cent and in the third, to about eight per cent.

Simultaneously, we formed still a third population by mixing seed of the varieties most typical of the race Celaya. This population for the purposes of our studies, is being called "Pure Celaya." Mass selection in this third population was started at the same time and is being carried on with the same intensity as in the Celaya-Exotic mixture.

Though these selection experiments were only recently initiated, considerable progress in yield improvement is already apparent in both the Celaya-Exotic mixture and the pure Celaya populations. At this stage of selection, yield in the former is noticeably higher than in the latter, and whether or not the two populations will eventually plateau at the same level remains to be seen. The one-acre plot of 8,000 plants of this composite in which the third cycle of selection was made, yielded 112 bushels of highly acceptable grain at 15.5 per cent moisture. In yield it appears to be well ahead of a plot of pure Celaya with the same number of cycles of mass selection. The Tuxpeño and Comiteco races seem to be contributing something of real value to the race Celaya, something which is already very apparent in the second generation of mass selection.

That substantial progress can be made through mass selection for yield is strikingly demonstrated by similar experiments we have under way in other areas. In the high Central Mesa of Mexico, the very productive race Chalqueño is widely distributed. Over 200 collections of this variety have been made and evaluated to date. Eighteen of the most productive varieties were crossed in all possible combinations. An equal amount of seed was taken from each of the resulting crosses and mixed. The F_2 of this mixture has been designated as Synthetic I. Mass selection was started immediately in the F_2 using the grid system described by Gardner (2). The population resulting from this first cycle selection was designated Synthetic II. The population resulting from the second cycle selection was designated Synthetic III, and that resulting from the third cycle of selection has been designated Synthetic IV. The yield of these four synthetics relative to the double cross hybrid H125 made from selected inbred lines of the race Chalqueño is shown in Table 3. Selection intensity in all cycles was about four per cent. As evident in Table 3, the average gain per generation of selection was about 10 per cent.

Similar results were obtained by Johnson and his colleagues (3) in a selection experiment in the race Tuxpeño at Cotaxtla in the State of Veracruz. After four cycles of selection in an open pollinated variety of this race (V520C) collected from a farm

TABLE 3
Yield of populations with different cycles of selection in the race Chalqueño (20 rep. 1965).

Variety	Yield in % of Synthetic I	Days to Half Silk
Synthetic I	100	106
Synthetic II	111	—
Synthetic III	123	—
Synthetic IV	130	107
Hybrid H125	135	107

near San Rafael, Veracruz, the resulting population (V520C-MS4) nearly equals the yield of the double cross H507 as evident in Table 4. The double cross H507 is the highest yielding hybrid in the San Rafael area and was made from selected inbred lines of the race Tuxpeño. According to data obtained by Johnson, the hybrid H507 yields about 35 per cent more than V520C. This would indicate an average gain of about eight per cent per cycle of selection in the population V520C.

One of the factors that appears to be contributing to greater yields in the Chalqueño population is an increase in prolificacy. By selecting plants on the basis of total weight of grain produced, the percentage of plants with tillers bearing good ears is becoming more frequent with each successive generation of selection.

TABLE 4
Comparative yields of H507 and V520C-MS4, San Rafael, Veracruz.

Variety	Yield in kg/ha[a] 1964A	1965A	Average	Av. Yield % H507
V520C-MS4	6,125	6,772	6,448	97.5
H507	6,208	7,015	6,612	100.0

[a] 1964A average of 32 replications; 1965A average of 8 replications.

The yield of a plant of this type is indicated below:

No. of tillers	3
No. of ears	5
Combined length of ears	75 cm
Average no. of rows	18
Total no. of kernels	2,596
Total weight of grain, 15.5% moisture	1,050 g

With results such as these, I am rapidly revolutionizing my thinking in regard to methods of corn breeding in the tropics. It looks as if the hybrid corn system of breeding is definitely premature for us in Latin America and that we might best devote our time and energies in the immediate future to: (1) the re-mixing of varieties within a race or of different races, and (2) the gradual concentration of the additive yield variance, in population so formed, by various relatively simple techniques of recurrent selection. After progress with this procedure ceases to be made, we might then resort to the use of the hybrid corn system of breeding in an attempt to gain further yield capacity through the utilization of whatever non-additive variance that may exist.

CARIBBEAN GERM PLASM OUTSTANDING IN COMBINATION WITH DENT VARIETIES

With this as a background, I should like to discuss the possibility of improving the Corn Belt Dents through the incorporation of certain elite exotic germ plasm complexes, not so much as a substitute for the hybrid corn system, but more so from the standpoint of developing new high yielding open pollinated varieties from which better hybrids can be made.

The Corn Belt Dents according to Brown and Anderson (1) were derived

from the inter-crossing of the Southern Dents and the Northern Flints. The origin of the Northern Flints is still obscure, but it is fairly certain that the Southern Dents consisted largely of Tuxpeño germ plasm which was moved north from the Gulf Coast lowlands of Mexico. From the chance inter-hybridization of these two types, an excellent, very productive race developed much like the way the high yielding races of Mexico came into being. If we can find something to add to the very productive races of Mexico to make them still more productive, we should be able to do the same with the Corn Belt Dents.

In my opinion, one of the most immediately useful varieties for the yield improvement of the Corn Belt Dents is a type obtained from the Island of Antigua in the West Indies. This variety is being preserved in the Mexican seed bank under the name of Antigua 2D and Antigua Group 2; the latter represents a composite of several collections. We have classified this material as being a variety of the race Coastal Tropical Flint described by Brown (4g). It produces relatively large ears with semi-flinty-floury yellow grain on sturdy stalks with short internodes, growing five to six feet tall under tropical day-length conditions, on fertile soil. Many plants bear two ears, but the variety itself does not appear to be particularly prolific. Tillers are generally absent. The plants in all aspects appear to be highly efficient producers of grain with a generally high ratio of grain to stalk for the tropics. It is earlier in maturity than the race Tuxpeño. It has certain defects which limit its immediate general use as a variety in the tropics. In the lowland high rainfall areas of Veracruz, it is very susceptible to a number of leaf diseases other than *Helminthosporium*. It is also not what we would consider as being highly resistant to root lodging.

In crosses with the tall, late, very vigorous Tuxpeño Dents, it has uniformly under a wide range of conditions exhibited a high degree of heterosis. In a yield test involving 210 diallel crosses among 21 selected varieties from the Caribbean and lowlands of Mexico, the crosses between a Yellow Tuxpeño Composite and Antigua 2D or the composite Antigua Group 2 were consistently among the highest yielding crosses at all three

TABLE 5

Performance of Antigua collections in crosses with Tuxpeño Yellow Dent.

Cross	Place tested	Yield kg/ha	Yield in % of Hiparent
Tuxp. Comp. A x Antigua 2D	Mexico	6,210	103
Tuxp. Comp. A x Antigua G2	Venezuela	6,310	137
Tuxp. Comp. A x Antigua 2D	Peru	4,339	134
Tuxp. Azteca x Antigua G2	Peru	6,487	134
Tuxp. Azteca x Antigua G2	Colombia	3,970	113
Tuxp. Azteca x Antigua G2	Brazil	3,880	115
Tuxp. Azteca x Antigua G2	Mexico T	3,000	122
Tuxp. Azteca x Antigua G2	Mexico C	2,200	126

locations. Yields of these crosses at the three different locations, Mexico, Venezuela and Peru, are shown in Table 5.

Furthermore, in a test of top crosses at five different locations, consisting of 46 varieties from the Caribbean top-crossed to a Yellow Tuxpeño variety named Azteca, the crosses with Antigua Group 2 were consistently among the highest yielding varieties at each location (Table 5).

Varieties from Antigua also combine well with the Corn Belt Dents. In a yield test of 18 of the better yielding Caribbean varieties crossed with the single cross WF_9 x B_7, conducted in Nebraska, Indiana and Argentina, the cross (WF_9 x B_7) x Antigua 2D ranked first, third and second in yield at the three locations, respectively. As evident in Table 6, its average yield for the three locations was six per cent higher than the average yield of the double cross hybrids included for comparison. In Nebraska and Indiana, comparisons were made with the double cross hybrid AES801 (WF_9 x B_7) (B10 x B14); in Argentina, with Pergamino Pita, a double cross developed at the Pergamino Research Station.

In another yield test containing 33 Caribbean varieties in combination with the single cross B10 x B14, conducted at the same three locations, the cross (B10 x B14) x Antigua 2D ranked first, fourth, and fifth in yield, respectively. Its average yield at the three locations was 12 per cent higher than the average yield of the double cross hybrids.

The double cross hybrids in these tests at each of the three locations were the same as those in the tests of crosses with WF_9 x B_7. Both the crosses WF_9 x B_7 and B10 x B14 with Antigua 2D flowered about five to seven days later than the hybrids in their respective areas.

This generally superb performance of the collections from Antigua in crosses with the dents is indicative of the general behavior of a broader complex of similar varieties found in the islands of the West Indies Federation. Collections from the islands of Guadalupe, Barbados and Saint Vincent are quite similar in type and maturity to those from Antigua. All are fairly typical of the Coastal Tropical Flint-Early Caribbean Flint racial complexes. The earlier varieties of this complex tend to be two-eared

TABLE 6

Relative yield of the single crosses WF_9 x B_7 and B10 x B14 in combination with three different exotic varieties, at two locations in the U.S.A. and one in Argentina.

Cross	Yield in per cent of adapted hybrids[a]			
	Nebraska	Indiana	Argentina	Average
(WF_9 x B_7) x Antigua 2D	99	117	103	106
(B10 x B14) x Antigua 2D	106	121	110	112
(WF_9 x B_7) x Florida Syn.	96	125	104	108
(B10 x B14) x Florida Syn.	96	104	111	104
(WF_9 x B_7) x Puerto Rico 24D	73	95	97	88
(B10 x B14) x Puerto Rico 24D	101	126	112	113

[a] Hybrid AES801 in Nebraska and Indiana; Pergamino Pita in Argentina.

TABLE 7

Caribbean varieties which in crosses with Azteca Yellow Dent ranked first, second or third in yield tests at different locations in Latin America.

Location	Varieties in: 1st place	2nd place	3rd place
Mexico—Tepal.	Saint Vincent 3D	Antigua 8D	Antigua 5D
Mexico—Cot.	Saint Vincent 3D	Antigua 5D	Granada 10D
Peru	Antigua 5D	Antigua 4D	Antigua 8D
Brazil	Jamaica 1J	Jamaica 4J	Cuba 4J
Argentina	Cuba 1J	Saint Vincent 3D	Guadalupe 1D

and are fairly prepotent in this character in crosses.

The high general combining ability of the varieties from this region as a whole with the Tuxpeño Dents is shown even more strikingly in Table 7. The varieties listed in this table were the best of 46 in top crosses with the Yellow Tuxpeño Dent variety Azteca and ranked either first, second or third in yield at the locations indicated.

All of the varieties appearing in this table represent different collections of the race Coastal Tropical Flint, except Cuba 4J, which is classified as Chandelle, and Jamaica 1J and 4J, which were classified as Cuban Flint Dent.

Another Caribbean germ plasm complex with good general combining ability, especially with the dents, is that which has been classified by Brown (4g) as the race Cuban Flint. Varieties of this race are generally later in maturity, with smaller and harder flinty seeds than the Coastal Tropical Flints. The grain is usually also of darker yellow or more of an orange-yellow color. This race probably originated from the inter-crossing of Coastal Tropical Flints with the introduced Argentine Flints.

A composite of two varieties of this race, Nariño 330 x Peru 330, has performed almost as well in crosses with the Tuxpeño Dents over a wide area as Antigua 2D (Table 8). Other good combiners of this race are Cuba 11J and a composite of Cuban Flint varieties designated as Cuba Group 1.

As may be seen in Table 9, the cross Antigua 2D x (Nariño 330 x Peru 330) exhibits considerable heterosis, although the F_1 yield generally runs about 10 to 15 per cent lower than either of these varieties in crosses with Tuxpeño.

TABLE 8

Performance of the Cuban Flint Composite Nariño 330 x Peru 330 in crosses with Tuxpeno Yellow Dent.

Cross	Place tested	Yield kg/ha	Yield in % of Tuxp. Comp. A
Tuxp. Comp. A x Nariño 330 x Peru 330	Mexico	6,145	101
Tuxp. Comp. A x Nariño 330 x Peru 330	Venezuela	5,540	120
Tuxp. Comp. A x Nariño 330 x Peru 330	Peru	3,921	121

TABLE 9

Heterosis in a cross of Coastal Tropical Flint x Cuban Flint.

Cross	Place tested	Yield F_1 kg/ha	Yield of F_1 in % of Midparent	Hiparent
Antigua 2D x (Nariño 330 x Peru 330)	Mexico	5,354	151	151
Antigua 2D x (Nariño 330 x Peru 330)	Venezuela	5,710	120	116
Antigua 2D x (Nariño 330 x Peru 330)	Peru	4,053	139	131

Other varieties that are of value are those of the West Indies Semi-Dent race, which are prevalent in Trinidad. These have repeatedly appeared in good yielding combinations in our evaluation studies, but have not been as consistent in their yields over a wide area as some of the others that have been indicated. They are generally late in maturity and much like the Tuxpeño Dents in growth habit in the tropics.

Also there are two other varieties shown in Table 6 which yielded well in combination with the single crosses $WF_9 \times B_7$ and B10 x B14 in the Corn Belt. These are: (1) a Florida Semi-Flint Synthetic, which Dr. Mario Gutierrez found to be an excellent combiner in his studies in Turrialba, Costa Rica (unpublished), and (2) Puerto Rico 24D, a collection which appears to belong to the complex which Brown (4g) described as Saint Croix Long Ear. According to the data in Table 6, there is a marked difference in combining ability of Puerto Rico 24D with the two single crosses $WF_9 \times B_7$ and B10 x B14.

The Florida Synthetic is Semi-Dent in its ear characteristics and probably represents a combination of the Cuban Flints or Coastal Tropical Flints with some of the Yellow Dent varieties of southern United States. The crosses with the Florida Synthetic flowered at about the same time as those with Antigua 2D, that is, five to seven days later than the hybrids. Crosses with Puerto Rico 24D were 10 to 12 days later in flowering than the hybrids.

Still another cross that performed well in tests in the United States of America is Cuba 16 x Corn Belt Dent Composite (CBC). Cuba 16 is a collection made in Cuba by E. Hernandez X. in 1949. It is a Cuban Semi-Flint variety. Its behavior in crosses with Corn Belt Dent at each of four different locations is shown in Table 10. This cross flowered from 10-12 days later than the hybrid AES801 in Nebraska and Indiana and from three to four days earlier than Dixie 82 in North Carolina and Mississippi. It was consistently high in yield at all locations. In the lists of 55 crosses with the Corn Belt Composite, in order of their yield at each of the locations, it ranked second in Nebraska,

TABLE 10

Yield of Cuba 16 x Corn Belt Composite at four locations in the U.S.A.

Location	Yield Bu./A.	Yield in per cent of: CBC	Hybrids[a]
Nebraska	100	124	108
Indiana	113	128	126
N. Carolina	92	123	88
Mississippi	74	245	112

[a] AES801 in Neb. and Ind.; in N. C., average of N. C. 288, N. C. 270 and Dixie 82; in Miss., average of Dixie 18, 22, 29, 33, 55, 77 and 82.

first in Indiana, second in North Carolina and third in Mississippi.

MEXICAN RACES OF VALUE

Although it is apparent that the Caribbean area is particularly rich in outstanding breeding materials for the improvement of the dent types, it would be a mistake to rely totally on races from this region.

Material from other areas should also be considered. In Table 11, 19 of the 25 described Mexican races are listed in order of their average yield score based on their average rank in yield with the single crosses WF_9 x B_7 and B10 x B14 in each of the tests made in Nebraska, Indiana, North Carolina, Mississippi and Mexico. The lower the score, the better the performance.

The race Harinoso de Ocho yielded uniformly well at all locations in combination with the two single crosses, with an average rank of 2.1. Average yield of (1) the crosses between this race and the two single crosses WF_9 x B_7 and B10 x B14 at all locations; (2) the hybrid AES801 under the same condition; and (3) the best yielding hybrids at each location, was 76, 74 and 86 bushels per acre, respectively.

The collection of Harinoso de Ocho used in these tests was Nayarit 24. It is more flinty than floury and probably represents a variety which originated from the introgression of Reventador in the floury, eight-rowed race described by Wellhausen, *et al.* (4a) as Harinoso de Ocho. This collection is representative of the varieties planted in November in the lowlands of Nayarit on alluvial river bottoms after the rainy season has ended.

It is interesting to note that the first nine races listed in Table 11, with the exception of Comiteco, are prevalent in the narrow strip of land between the mountains and the Pacific Ocean along the western and southern coasts of Mexico. Comiteco is prevalent around Comitan in Chiapas, in a valley of about 1,500 m elevation in the Isthmus of Tehuantepec. All these varieties, with the possible exception of Comiteco, have

TABLE 11

Average yield score of 19 Mexican races in combination with WF_9 x B_7 and B10 x B14 tested in Neb., Ind., N. C., Miss. and Mexico.[a]

Race	Score	Race	Score
1. Harinoso de Ocho	2.1	11. Zapalote Chico	9.5
2. Zapalote Grande	4.0	12. Chalqueño	9.6
3. Vandeño	4.4	13. Maiz Dulce	9.7
4. Reventador	4.4	14. Cacahuazintle	10.0
5. Comiteco	6.0	15. Conico	10.3
6. Tabloncillo	6.7	16. Arrocillo Amarillo	10.8
7. Tepecintle	6.7	17. Pepitilla	11.7
8. Nal-Tel	6.7	18. Oloton	11.9
9. Chapalote	7.0	19. Tehua	15.3
10. Bolita	7.5		

[a] The lower the score the better the performance.

TABLE 12

Comparative performance of four Mexican races in combination with Indiana Synthetic B.

Cross	Av. yield Bu./A.	Height to tassel	Height to ear	Days to half silk
Synthetic B x Harinoso de Ocho	108	92	47	75
Synthetic B x Reventador	109	107	57	82
Synthetic B x Eto	102	118	61	88
Synthetic B x Tuxpeño	124	125	62	90
Synthetic B	43	81	34	77
Oh 45 x Oh 43	112	86	40	74

been influenced by the primitive Nal-Tel-Chapalote Complex. A very distinct chromosome knob found in the race Chapalote is present in most of these races and extends south into the Salvadoreño race of the southern lowlands of Guatemala and El Salvador.

According to these data, the races of western and southern Mexico may have something of value to contribute to the further improvement of the Corn Belt Dents or to the Gulf Coast Dents of Mexico. The interracial cross Harinoso de Ocho x Tuxpeño exhibits considerable heterosis, yielding about the same as the Hybrid H507 in Veracruz.

Mexican races not included in the above list are: Palomero Toluqueño, Conico Norteño, Jala, Celaya and Tuxpeño. Of these, the latter has been found to be an excellent combiner, not only with Coastal Tropical and Cuban Flints but also with the synthetic variety Eto of Colombia and, according to data in Table 12 obtained by O. E. Nelson of Purdue, with Corn Belt Dent germ plasm. The high yield of the cross Synthetic B and Tuxpeño in this test agrees with earlier work by Nelson (to my knowledge, unpublished) in which he found that Tuxpeño germ plasm incorporated into some of the Indiana hybrids in small doses, remarkably raised the yield of these hybrids.

USEFUL RACES OF SOUTH AMERICA

So far, verv little work has been done in the systematic evaluation of the races of South America. As I have already mentioned, the synthetic variety Eto developed by Eschavariaga in Colombia combines excellently with Tuxpeño. Crosses between Eto and varieties of the Tuxpeño race have uniformly performed equal to or better than the hybrids available in the different lowland areas of tropical Latin America. I have seen crosses in Peru between some of the high altitude varieties prevalent there and certain varieties of Corn Belt Dent, which performed surprisingly well. Based on my own observations, I believe the races Ancashino, Marañon, Chullpi and the Cuzqueño Complex might have something useful in them. Marañon is a race that appears to have developed from the introgression of the interlocked types of the Amazonian lowlands described by Brieger *et al.* (4e) into the highland varieties of the Andes.

CONCLUSIONS AND RECOMMENDATIONS

Although the available data may as yet not be very concrete or precise, I believe the possibilities for the further improvement of corn through a more complete exploitation of the many different germ plasm complexes existing in the tropics are extremely great. The additive variance for yield distributed among the over 300 different races of maize in Latin America is enormous. If in some way more of this could be concentrated in a single race, I believe we would be in a better position to develop some real super varieties in the future and would probably bring about an even greater revolution of maize production throughout the world than that which has occurred in past years.

One way of proceeding would be by mixing together all the different races now available and gradually concentrating the additive variance in this hodge-podge through mass selection. Although we may attempt to do this somewhere in the tropics in a neutral environment, I do not believe this would be immediately useful for the further improvement of the yield capacity of maize in the Corn Belt. Judging from present yields, maize in the Corn Belt is already fairly good, and it seems to me the best way to proceed in an attempt to make it still better would be to look for additional genes favorable for yield which are not now present and which may be incorporated without loss of others. I fully realize that it is rather difficult to identify these genes, and if we could identify them we would most likely not find them in a single exotic variety. This, however, should not keep us from attempting to move ahead. We know that certain germ plasm complexes offer greater possibilities than others, and we ought to start with these.

In view of the results obtained from the limited evaluation studies conducted in Latin America and in the Corn Belt of the United States, I would like to suggest that four germ plasm pools be made up each with the following exotic races:

Pool 1—Caribbean
- Tuxpeño—(Mexico)
- West Indies Semi-Dent
- Chandelle
- Coastal Tropical Flint
- Cuban Flint
- Eto—(Colombia)

Pool 2—Mexican West Coast Lowlands
- Harinoso de Ocho
- Zapalote Grande
- Tepecintle
- Reventador
- Chapalote
- Nal-Tel

Pool 3—Mexico Highlands
- Comiteco
- Pepitilla
- Chalqueño
- Maiz Dulce
- Cacahuazintle

Pool 4—Andean Highlands
- Ancashino—Peru
- Marañon—Peru
- Cuzqueno—Peru
- Chullpi—Peru
- Oloton—Comiteco (Guatemala)

In the development of these pools, each race should be crossed with a Corn Belt Dent Composite (or in certain cases a specific single cross may be used). Each of the resulting crosses should be backcrossed to the Corn Belt composite. Backcrosses corresponding to a particular pool should then be crossed in all possible combinations, and the basic population

for each pool established, by mixing equal quantities of seed of each of the respective diallel crosses. This should be followed by several generations of random mating within each pool. How many generations of genetic mixing one should attempt before taking off with other procedures I do not know, but I would suggest at least five. The amount of mixing needed before the population is subjected to selection pressures will no doubt vary with the different pools.

Once a reasonable amount of mixing has taken place, an attempt should be made to concentrate the additive variance through mass selection, with the selection based on individual plant grain yield without bias in regard to the shape or form of the plant.

This on the surface appears to require a lot of time, but actually I believe the number of years involved in getting a particular pool ready for mass selection could be greatly reduced through a well organized cooperative effort on the part of those interested. By making use of the many natural "phytotrons" available in the Latin American tropics, readily two and maybe three generations per year could be obtained. Crossing and mixing could be done outside of the Corn Belt or in an alternating program between the Corn Belt and the tropics.

In the attempt to incorporate additional favorable genes into the Corn Belt Dents through the use of exotic unrelated materials, I think it is important to start with small doses of such materials. Twenty-five per cent as suggested above may even be too much, but until more precise information is available, I believe it is a good place to begin.

I do not wish to minimize the problems that may be involved in the genetic mixing of unrelated germ plasms, but on the basis of my own experiences I believe that, although some of our efforts in getting a product of greater economic importance through the use of exotic germ plasm may be thwarted through linkage restrictions, you will be surprised as to how large the dividends will actually be from a program of this kind.

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