on male-sterile plants was directly related to the frequency of pollinators in the population, regardless of the number of cross-pollinations per plant.

These data indicate that in the intercrossing or recombination blocks where genetic male-steriles were used, cross-pollinations to male-sterile plants were directly related to the frequency of each genotype in the recombination block. A random assortment of genotypes in such a population would insure random pollination of the male-sterile plants. The incidence of cross-pollinations on individual male-sterile plants was directly related to the genotypes in the population irrespective of the number of seeds produced on these plants.

The data also suggest that foreign genes could be readily introgressed into an intermating population containing male-steriles by simply blending seeds of the foreign germplasm with seeds used to produce the intermating population. The foreign genes would be introgressed into the population in relation to the amount of seed blended with seed of the intermating population. This would be a simple, convenient method of incorporating unique genes for superior agronomic characteristics or pest resistance into existing, intermating populations.

REFERENCES

1. Bernard, R.L. and C.R. Cremeens. 1975. Inheritance of the Eldorado male-sterile trait. Soybean Genet. Newsl. 2:37–39.
2. Boerma, H.R., and A. Moradshahi. 1975. Pollen movement within and between rows of male-sterile soybeans. Crop Sci. 15:858–861.
3. Brim, C.A., and C.W. Stuber. 1973. Application of genetic male sterility to recurrent selection schemes in soybeans. Crop Sci. 13:528–530.
4. Caviness, C.E. 1966. Estimates of natural cross pollination in Jackson soybeans in Arkansas. Crop Sci. 6:211–212.
5. Jaycox, E.R. 1970a. Ecological relationships between honey bees and soybeans. II. The plant factors. Am. Bee J. 110:343–345.
6. ----. 1970b. Ecological relationships between honey bees and soybeans. III. The honey-bee factors. Am. Bee J. 110:383–385.
7. Nelson, R.L., and R.L. Bernard. 1979. Pollen movement to male sterile soybeans in southern Illinois. Soybean Genet. Newsl. 6:100–103.
8. ----, and R.L. Bernard. 1984. Production and performance of hybrid soybeans. Crop Sci. 24:549–553.
9. St. Martin, S.K. 1981. A new recurrent selection scheme incorporating genetic male sterility. Soybean Genet. Newsl. 8:107–109.
10. Weber, C.R., and W.D. Hanson. 1961. Natural hybridization with and without ionizing radiation in soybeans. Crop Sci. 1:389–392.
11. Woodworth, C.M. 1921. Inheritance of cotyledon, seed-coat, hilum, and pubescence color in soy-beans. Genetics 6:487–553.

Testcross Evaluation of Mexican Maize Populations[1]

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ABSTRACT

Maize(*Zea mays* L.) breeders in the USA have emphasized selection in less than 5% of the total available maize germplasm. Although genetic gains have been made within races of maize adapted to the USA, there is interest in expanding the germplasm base available to applied breeding programs. Our objective was to evaluate the relative potential of improved Mexican germplasm in testcrosses with two U.S. Corn Belt populations. Field trials were conducted in eight environments in Mexico and four environments in the western U.S. Corn Belt in 1982 and included 24 Mexican populations crossed with U.S. Corn Belt adapted testers, BS13(S)C3 and Lancaster Composite. Few individual crosses yielded significantly better than the testers in the U.S. Corn Belt. Grain moisture at harvest, ear height, and days-to-flower were greater in crosses compared with testers per se. The BS13(S)C3 testcrosses had significantly greater yields than Lancaster testcrosses, but grain moisture at harvest, ear height, and lodging were not significantly different between the two sets of testcrosses. Both sets of testcrosses yielded significantly more than the checks in Mexico, suggesting that elite selections could be obtained for use in Mexico breeding programs. Crosses with BS13(S)C3 seemed to be more promising than crosses with Lancaster Composite in Mexico. Across 7729 and Poza Rica 7822 were the only Mexican populations that had significant estimates of general combining ability in both countries.

***Additional index words:* *Zea mays* L., Exotic germplasm, Recurrent selection, Germplasm evaluation.**

MAIZE (*Zea mays* L.) breeders in the USA have made genetic gains that emphasized selection within races of maize adapted to this country (Russell, 1974; Duvick, 1977). Brown (1975) reported that U.S. maize breeders have emphasized selection in only two or three races (less than 5% of the total available maize germplasm). Although U.S. maize breeders have effectively used a limited sample of maize germplasm, there is concern whether the current rates of genetic advance can continue. Hence, there is considerable interest in expanding the germplasm base available to applied breeding programs in the USA. Maize breeders in Mexico have a greater range of germplasm available than their counterparts in the USA. Although the Mexican maize breeders have access to a tremendous range of germplasm, much of the material has not been under selection designed

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to meet the level of performance required by modern producers. Recently, improved germplasm sources have become available in the tropical areas (Paliwal and Sprague, 1981). These improved tropical populations are of interest to breeders in Mexico and the USA because they may be useful in expanding the germplasm base of breeding programs in both countries. Additionally, the highly productive dent cultivars of the U.S. Corn Belt may contribute useful genes to Mexican breeding materials.

The primary objective of our study was to determine the relative performance of 24 Mexican populations in testcrosses with two U.S. Corn Belt populations in northeastern Mexico and the western U.S. Corn Belt.

MATERIALS AND METHODS

Materials used in this study included 20 populations developed by breeders of the International Maize and Wheat Improvement Center (CIMMYT) and their cooperators, two open-pollinated cultivars developed by breeders of the National Institute of Agricultural Investigations (INIA), and two populations developed by breeders of the Antonomous Agrarian University "Antonio Narro" (UAAAN) (Table 1). Some of the populations included worldwide germplasm collections, whereas others included mixtures of South American, Caribbean, Central American, and Mexican races of maize (CIMMYT, 1982). Each of the 24 populations was crossed to two testers, BS13(S)C3 and Lancaster Composite. The BS13(S)C3 is an improved strain of 'Iowa Stiff Stalk Synthetic' developed by seven cycles of half-sib recurrent selection and three cycles of S_1 or S_2 recurrent selection (Hallauer and Smith, 1979). Hereinafter, this population will be referred to as BS13. Lancaster Composite was developed by crossing 15 inbred lines that included 'Lancaster Sure Crop' germplasm to three populations [BSTL(S2)C2, BSL(SR)C6, and BSL(HI)C5] that included Lancaster germplasm and had been improved by recurrent selection (Clucas, 1984).

Testcrosses were produced at the INIA Research Station near Tancasneque, Tamaulipas, Mexico, during the 1980 winter season in two separate isolation fields. The populations were detasseled and crossed by open-pollination to the respective testers. Each population was grown in a six-row plot 30 m long. Ears from about 150 plants were harvested from each plot, shelled, and seed was thoroughly mixed before a sample was taken for the yield trials.

Testcrosses were evaluated in two sets of experiments conducted in northeastern Mexico and at four locations in the western U.S. Corn Belt in 1982. The first set of experiments in Mexico was conducted at Rio Bravo, Tam.; Las Adjuntas, Tam.; Anahuac, N.L.; and Rio Verde, S.L.P. These experiments included the 48 testcrosses, one check hybrid, and BS13 and Lancaster Composite. The experimental design was a 7 × 7 simple lattice with BS13 and Lancaster Composite randomly included between subblocks. Plot size was one 4-m row with 0.8 m between plots. The second set of experiments included the 48 testcrosses, BS13, Lancaster Composite, and 31 checks, and test locations were Rio Bravo (seocnd planting date); Las Adjuntas (second planting date); Tancasneque, Tam.; and Rio Verde (second planting date). The experimental design was a 9 × 9 simple lattice, and plot size was two rows 4 m long with 0.8 m between rows. In both sets of experiments, the final stand was about 62 500 plants ha^{-1}. Data collected for the two sets of experiments included yield (10 competitive

Table 1. Average grain yields of 24 Mexican populations crossed to BS13(S)C3 and Lancaster Composite grown at eight environments in Mexico and four environments in the U.S. Corn Belt in 1982.

	Grain yield								
	Mexico			U.S. Corn Belt			Combined		
Population	BS13	Lanc. comp.	$\overline{X}$	BS13	Lanc. Comp.	$\overline{X}$	BS13	Lanc. Comp.	$\overline{X}$
	Mg ha^{-1}								
Poza Rica 7822	7.86 (4)‡	6.76 (5)	7.31 (4)	7.07 (2)	5.95 (1)	6.51 (2)	7.60 (1)	6.49 (2)	7.04 (1)
Poza Rica 7843	7.40 (11)	6.96 (3)	7.18 (5)	6.88 (4)	4.91 (16)	5.90 (7)	7.23 (9)	6.27 (9)	6.75 (5)
Across 7832	8.10 (2)	6.86 (4)	7.48 (1)	6.21 (17)	4.88 (18)	5.55 (15)	7.47 (2)	6.20 (2)	6.83 (3)
Across 7729	7.76 (5)	7.02 (1)	7.39 (2)	6.90 (3)	5.20 (11)	6.05 (6)	7.47 (3)	6.41 (3)	6.94 (21)
Across 7734	6.61 (23)	6.73 (6)	6.67 (16)	6.32 (14)	5.42 (9)	5.87 (9)	6.51 (23)	6.30 (5)	6.40 (15)
Across 7642	6.58 (24)	6.55 (10)	6.58 (22)	7.15 (1)	5.93 (3)	6.54 (1)	6.77 (17)	6.34 (4)	6.56 (9)
Across 7644	7.49 (9)	6.53 (12)	7.02 (7)	6.74 (6)	5.48 (7)	6.11 (5)	7.24 (7)	6.19 (10)	6.71 (6)
Tuxpeno Planta Baja C17	7.21 (13)	6.10 (18)	6.66 (17)	6.08 (19)	4.91 (17)	5.50 (19)	6.84 (14)	5.70 (20)	6.27 (21)
ETO Blanco Seleccion EF	7.21 (14)	6.07 (19)	6.64 (19)	6.66 (7)	5.86 (4)	6.26 (3)	7.03 (11)	6.00 (14)	6.51 (12)
PPMG	7.44 (10)	6.06 (20)	6.75 (14)	5.55 (22)	5.52 (6)	5.53 (17)	6.81 (15)	5.88 (16)	6.35 (19)
(Mix-1 × Cal. Gpo. 1) ETO	8.10 (1)	6.68 (8)	7.39 (3)	5.52 (23)	4.67 (20)	5.10 (24)	7.24 (8)	6.01 (13)	6.63 (7)
Tuxpeno Caribe 1	7.91 (3)	6.03 (21)	6.97 (10)	6.00 (20)	4.58 (22)	5.29 (22)	7.27 (6)	5.55 (22)	6.41 (14)
Tuxpeno Caribe 2	7.70 (6)	5.87 (23)	6.78 (12)	6.65 (8)	5.07 (13)	5.86 (10)	7.35 (5)	5.67 (21)	6.51 (11)
Braquitico	6.93 (18)	7.00 (2)	6.96 (11)	5.01 (24)	5.95 (2)	5.48 (20)	6.29 (24)	6.65 (1)	6.47 (13)
Blanco Cristalino	7.70 (7)	6.53 (13)	7.11 (6)	6.75 (5)	5.73 (5)	6.24 (4)	7.38 (4)	6.26 (7)	6.82 (4)
Tuxpeno PB × ETO PB	6.89 (20)	6.37 (14)	6.63 (20)	6.29 (16)	4.63 (21)	5.46 (21)	6.69 (20)	5.79 (19)	6.24 (22)
V-401†	6.70 (22)	6.60 (9)	6.65 (18)	6.33 (13)	5.45 (8)	5.89 (8)	6.58)21)	6.22 (8)	6.40 (16)
V-402†	7.06 (15)	6.27)16)	6.67 (15)	6.48 (10)	4.98 (15)	5.73 (11)	6.87 (13)	5.84 (17)	6.35 (18)
AED × Tuxpeno	7.01 (16)	6.22 (17)	6.62 (21)	6.42 (11)	4.99 (14)	5.71 (13)	6.81 (16)	5.81 (18)	6.31 (20)
SSE(MH)B C3§	6.70 (21)	5.48 (24)	6.09 (24)	6.21 (18)	4.24 (24)	5.23 (23)	6.54 (22)	5.06 (24)	5.80 (24)
SSE(MH)A C3§	6.90 (19)	5.88 (22)	6.39 (23)	6.51 (9)	4.54 (23)	5.53 (18)	6.77 (18)	5.43 (23)	6.10 (23)
Pool 19	7.30 (12)	6.70 (7)	7.00 (8)	6.36 (12)	5.09 (12)	5.73 (12)	6.99 (12)	6.16 (11)	6.58 (8)
Pool 20	6.98 (17)	6.54 (11)	6.76 (13)	6.32 (15)	4.78 (19)	5.55 (16)	6.76 (19)	5.96 (15)	6.36 (17)
Blanco Dentado-2	7.60 (8)	6.37 (15)	6.99 (9)	5.97 (21)	5.36 (10)	5.67 (14)	7.05 (10)	6.03 (12)	6.54 (10)
Mean of testcrosses	7.30	6.42	6.86	6.35	5.18	5.77	6.98	6.01	6.50
Testers per se	2.68	3.74	3.21	6.06	4.64	5.35	3.81	4.04	3.93
Checks			6.59			7.93			7.04
LSD (0.05)	0.85	0.85	0.60	0.99	0.99	0.70	0.65	0.65	0.46
CV (%)			18.18			17.36			18.05

† Population developed by breeders of INIA. ‡ Numbers within parentheses indicate relative ranking. § Population developed by breeders of UAAAN.

plants, expressed as Mg ha^{-1} of grain at 15.5% grain moisture), grain moisture content at harvest (%), number of days from planting to 50% pollen shed, ear height (cm, measured from ground level to the node bearing the top ear), and ears per plant (number of ears harvested per plot divided by the number of plants).

The four sites chosen for testing in the U.S. Corn Belt included Lincoln, NE.; Ames and Martinsburg, IA.; and Columbia, MO. The experiment at Lincoln included the 48 testcrosses, the two check hybrids, and the experimental design was a randomized complete block with two replications. Plot size was two rows 4.9 m long with 0.76 m between rows. Experiments at Ames, Martinsburg, and Columbia included 64 entries (the 48 testcrosses, the two testers, four check hybrids, and 10 check entries). Plots were two rows 5.5 m long with 0.76 m between rows arranged in an 8 × 8 simple lattice design. All plots were machine planted and harvested. Data were recorded per plot for number of days from planting to 50% pollen shed at Ames and Lincoln; ear height at Ames, Columbia, and Lincoln; percentage of dropped ears at Ames, Lincoln, and Martinsburg; and grain yield (adjusted to 15.5% moisture), grain moisture content at harvest, and percentage of root lodging (plants leaning more than 30° from the vertical) and stalk lodging (plants broken at or below ear node) at Ames, Columbia, Lincoln, and Martinsburg.

Analyses of variance were computed for each experiment, and data were combined across experiments within each country. Analyses of variance were computed that included the check entries and then reanalyzed with the check entries omitted because different check entries, experimental designs, and traits measured were used in the individual experiments. Because of some missing plots for check entries in Mexico, and because the efficiency of the lattice analysis relative to the randomized complete block analysis was minimal in the U.S. Corn Belt, a randomized complete-block analysis was used for all experiments. A combined analysis of variance for each trait was computed from the data obtained in both countries.

For the individual combined analyses, the sums of squares for testcrosses were subdivided to include orthogonal and nonorthogonal contrasts. The first partitioning was to obtain information on populations by tester interactions, between testers, and among populations comparisons. Specific (s_{ij}) and general (g_i) combining ability effects of the testcrosses and parents (populations and testers), respectively, also were estimated from this type of analyses. The second subdivision of the testers sum of squares was to provide information on variation among testcrosses to a given tester and to make other comparisons. In all the combined analyses, a corresponding subdivision of the genotype × environment (location and/or country) interaction sum of squares also was possible for both previously mentioned subdivisions.

RESULTS AND DISCUSSION

U. S. Corn Belt

Differences among entries were significant (P 1≤ 0.01) for grain yield (all locations), grain moisture (Lincoln, Ames, and Columbia), root lodging (Lincoln), stalk lodging (Columbia and Martinsburg), dropped ears (Martinsburg), ear height (Lincoln, Ames, and Columbia), and days-to-pollen shed (Ames) in the combined analysis (not shown). The interactions of entries with locations were not significant for grain yield, grain moisture, and root and stalk lodging. Combined analyses for the other three traits were not computed.

Partitioning of the testers sum of squares of the combined analyses into among BS13 and Lancaster composite testcrosses showed that the variation within the two sets of testcrosses was significant for all traits except grain moisture (BS13 testcrosses) and stalk lodging(both testers). Orthogonal comparisons of means for the two sets of testcrosses and the two testers showed that the BS13 testcrosses had significantly less root lodging than BS13, that Lancaster Composite testcrosses had significantly greater grain moisture than Lancaster Composite, and that BS13 testcrosses were significantly greater yielding than the Lancaster Composite testcrosses. All other comparisons among traits were nonsignificant. There were no significant interactions for Lancaster Composite testcrosses with the four U.S. Corn Belt locations, whereas the BS13 testcross by location interactions were significant for yield and grain moisture. Subdivision of the entries sums of squares of the combined analyses into testers, populations, and population × tester interactions showed that the population × tester interactions were not significant except for plant stand. This result suggests that the relative performance of the Mexican populations in testcrosses was similar for the two adapted testers.

The variation among Mexican populations in testcrosses was significant for yield, grain moisture, and root lodging, whereas the two testers in crosses to the Mexican populations were significantly different only for yield. There were significant population × tester interactions with the U.S. Corn Belt locations for yield and root lodging. The Mexican population × location interactions were significant only for root lodging and stalk lodging.

At Lincoln, NE., all BS13 testcrosses (8.21 Mg ha^{-1} with 24.4% grain moisture) exceeded the adapted BS13 population in yield (6.03 Mg ha^{-1} with 19.1% grain moisture), and 15 exceeded the mean of the check hybrids (8.21 Mg^{-1} with 18.2% grain moisture). The greatest-yielding testcross (BS13 × Blanco Cristalino) produced 9.67 Mg ha^{-1} with 24.1% grain moisture. Overall at Lincoln, the BS13 crosses yielded 36% more than BS13 per se (8.21 Mg ha^{-1} vs. 6.03 Mg ha^{-1}). The Lancaster Composite testcrosses had only 7.3% higher yields compared with Lancaster Composite per se (6.49 Mg ha^{-1} vs. 6.05 Mg ha^{-1}). None of the Lancaster Composite testcrosses exceeded the check hybrids. BS13 and Lancaster Composite, however, yielded about the same (6.03 Mg ha^{-1} and 6.05 Mg ha^{-1}, respectively) at Lincoln, whereas BS13 yielded 60% higher at Ames and Martinsburg and 20% higher at Columbia.

The testcrosses had significantly greater grain moisture than the testers or the check hybrids (Table 2). Differences among locations were significant, but the relative performance of genotype groups changed little among locations. Root and stalk lodging varied greatly among locations. Overall, testcrosses tended to be higher in root lodging but lower in stalk lodging than the testers per se. The check hybrids tended to be lower for root and stalk lodging.

Table 2. Average performance of BS13(S)C3 and Lancaster Composite per se and in testcrosses to 24 Mexican populations evaluated for seven traits in four U.S. Corn Belt environments and for five traits in eight Mexican environments in 1982.

Country	Entries	Grain		Lodging		Ears		Ear height	Days to flower
		Yield	Moisture	Root	Stalk	Dropped	Per plant		
		Mg ha⁻¹	%				no.	cm	no.
USA	BS13(S)C3	6.06	20.8	13.9	34.2	0.9	–†	109	81
	Lancaster Composite	4.64	22.5	3.4	42.6	0.0	–	107	77
	BS13(S)C3 testcrosses	6.35	27.0	13.5	22.7	0.7	–	149	86
	Lancaster Composite testcrosses	5.18	26.8	15.5	23.1	1.1	–	148	85
	Check hybrids	7.93	20.7	10.9	22.0	0.6	–	116	78
	$s_{\bar{x}}$‡	0.36	0.7	3.4	4.0	0.6		3.3	0.7
Mexico	BS13(S)C3	2.69	13.0	–†	–†	–†	0.75	70	66
	Lancaster Composite	3.74	12.9	–	–	–	0.86	80	63
	BS13(S)C3 testcrosses	7.29	15.4	–	–	–	0.96	93	64
	Lancaster Composite testcrosses	6.42	15.0	–	–	–	0.94	93	64
	Check hybrids	6.59	16.9	–	–	–	0.95	118	68
	$s_{\bar{x}}$	0.30	0.2				0.30	2.8	0.7

† Data were not taken. ‡ Standard errors were calculated on basis of entry means.

Previous research has shown some instances of increased yields in exotic × adapted crosses as compared with their individual parents, (Moll et al., 1962; Moll et al., 1965; and Wellhausen, 1965). The increase is attributed to the hybrid vigor resulting from the genetic diversity of the exotic and adapted populations. Kramer and Ullstrup (1959), Efron and Everett (1969), and Lonnquist (1974), however, found no significant increase in yields after introgression of exotic germplasm. The testcrosses in our study also had higher yields than the adapted parent populations, but these yields were not significantly different. Although yields do not always improve when exotic germplasm is integrated into adapted germplasm, other benefits may result. Bruce and Lindstrom (1954) and Wellhausen (1965) reported increased general combining abilities of exotic × adapted populations compared with that of the adapted parent population. This combining ability is important when the interpopulation crosses involving exotic germplasm are used as sources of inbred lines for conventional hybrids where good general and specific combining abilities are necessary.

Mexico

For the eight experiments conducted in Mexico, significant differences were found among entries, except for yield at Las Adjuntas (second planting date), grain moisture at Las Adjuntas (second planting date) and Anahuac, days-to-pollen shed at Tancasneque and Rio Verde (first planting date), ear height at Rio Verde (second planting date) and Las Adjuntas (first planting date), and for ears per plant at all locations. Combined analyses of variance detected significant differences among entries for all the traits measured. The entry × environment interactions were significant for yield, grain moisture, and days to pollen shed. For the combined analyses, variation among testcrosses to a given tester was significant except for ears per plant.

Orthogonal comparisons of means for the two sets of testcrosses revealed responses similar to those in the U.S. Corn Belt; i.e., BS13 testcrosses were significantly greater yielding and later maturing than the Lancaster Composite testcrosses. For grain yield, there also were no significant interactions for Lancaster Composite testcrosses with the eight Mexican environments, whereas the BS13 testcrosses × environment interactions were significant. Significant genotype × environment interactions for grain moisture were detected in both sets of testcrosses. Lancaster Composite testcrosses showed significant interactions with environments for days to pollen shed. Contrary to the U.S. Corn Belt results, the population × tester interactions were significant for yield and grain moisture, days to pollen shed, and ear height. One possible explanation for this differential response is that the Mexican environments were less limiting for the normal phenological development of the testcrosses studied than the sample of locations chosen for testing in the U.S. Corn Belt. Variation among Mexican populations in testcrosses and among testers in crosses to the populations was significant for all traits except for ear height (testers) and for ears per plant (populations). Populations and testers showed significant interactions with environments for yield, grain moisture, and days to pollen shed. The population × tester interactions were not significant except for grain moisture. With only one exception (Rio Bravo, first planting date), the two sets of testcrosses exceeded the yield of their respective testers (Table 2). This type of response was expected because the two testers were developed for environmental conditions considerably different from the ones prevailing in Mexico where the tests were conducted.

On the average, yields at the eight Mexican environments were higher for the BS13 testcrosses as compared with the Lancaster Composite testcrosses. The differences between BS13 and Lancaster Composite per se, however, were not significant in most instances. Several testcrosses yielded significantly greater than the checks in all the environments (Table 1). The possibility exists of obtaining superior Mexican selections by incorporating U.S. Corn Belt germplasm into Mexican populations adapted to northeastern Mexico. Oyervides-Garcia et al. (1985) reached similar conclusions for some tropical and subtropical areas of Jalisco and Veracruz, Mexico. In their study, U.S. Corn Belt germplasm per se performed better than in this study.

Differences in grain moisture, days to pollen shed, and ear height between testcrosses and checks were not so large as the ones detected for the tests conducted in the U.S. Corn Belt (Table 2). Photoperiodic response of the Mexican populations, which resulted in taller plants and delayed maturity, probably was the main explanation for these differences.

Significant differences were detected among testcrosses to a given tester for yield, grain moisture, ear height, and days to pollen shed. Orthogonal comparisons revealed significant differences between the two sets of testcrosses for yield and grain moisture. On the average, BS13 testcrosses had greater yield and grain moisture than Lancaster Composite testcrosses (Table 1). Significant differences for yield and ear height were not detected between testers for grain moisture and days to pollen shed (Table 2).

Mexico and U.S. Corn Belt

Significant differences were detected among entries for most traits in the individual analyses of variance in both countries (not shown). Grain yields for the 24 Mexican populations crossed to each tester, yields averaged over testers for each country, and yields averaged over the two testers are summarized in Table 1. Some testcrosses produced greater grain yields than the adapted parent populations. Poza Rica 7822, for example, had an average yield (7.04 Mg ha^{-1}) across test locations and testers that was equal to the average yield of the checks (Table 1). Check hybrids, however, consistently yielded more than the testcrosses. The yields for the two sets of testcrosses were not significantly greater than their respective testers per se when considered across locations (Table 2).

The interactions of testcrosses to a given tester with countries were significant for all traits except for ear height (BS13 testcrosses) and yield (Lancaster Composite testcrosses). Grain yields for the Lancaster Composite testcrosses were relatively consistent for the two test areas but not for the BS13 testcrosses. Variation among Mexican populations in testcrosses and among testers in crosses to those populations was significant except for ear height (testers). The population × country and tester × country interactions were significant for all the traits except for grain moisture and ear height (tester × country interaction), but the tester × population × country interactions were significant for only grain moisture.

Spearman's rank correlations, calculated from the data presented in Table 1, showed a lack of correspondence between rankings of BS13 testcrosses in Mexico and in the U.S. Corn Belt (r = -0.033), which was opposite to the significant correspondence of rankings by the Lancaster Composite testcrosses (r = 0.361, at the 0.01 level). Within countries, there was some correspondence in ranking between the BS13 and the Lancaster Composite testcrosses [r = 0.123 (0.05 level) for Mexico and r = 0.355 (0.01 level) for the U.S. Corn Belt], but the correlations have essentially no predictive value.

General and specific combining ability estimates were estimated from the means included in Table 1. Across 7832 (ETO germplasm; CIMMNYT, 1982), Across 7729 (Tuxpeno Caribe germplasm; CIMMYT, 1982), [Mix. 1 × Col. Gpo. 1] ETO, and Poza Rica 7822 (Tuxpeño-ETO-Caribbean-Central America germplasm; CIMMYT, 1982), had the highest significantly positive g_i estimates for Mexico. For the U.S. Corn Belt, Across 7642 (ETO-Illinois germplasm; CIMMYT, 1982), and Poza Rica 7822 had significantly positive g_i estimates with ETO Blanco Selection EF (0.50 ± 0.26) and Blanco Cristalino (0.48 ± 0.26) approaching significance. Combining the information from both countries, Poza Rica 7822 (0.55 ± 0.17) and Across 7729 (0.45 ± 0.17) had significantly positive g_i estimates with Poza Rica 7843 (0.26 ± 0.17), Across 7832 (0.34 ± 0.17), and Blanco Cristalino (0.33 ± 0.17) having positive estimates of g_i approaching significance. On the basis of the relative magnitude of the s_{ij} estimates, the best crosses for Mexico, were Tuxpeño Caribe-1, Tuxpeño Caribe-2, [Mix. 1 × Col. Gpo. 1] ETO, and PPMG (selection for small plants and large ears, E.C. Johnson, 1984, personal communication) with BS13, and Across 7734 (subtropical broad genetic base germplasm; CIMMYT, 1982), Braquitico, Across 7642, and V-401 with Lancaster Composite. However, all s_{ij} estimates were not significant. For the U.S. Corn Belt, Poza Rica 7843, SSE(MH)BC3, SSE(MH)- AC3, and Across 7729 in crosses to BS13 and Braquitico, PPMG, and Blanco Dentado-2 (Tuxpeño germplasm; CIMMYT, 1982) in crosses to Lancaster Composite had the largest s_{ij} estimates.

These results suggest that elite selections can be obtained from recombinations between the U.S. Corn Belt and Mexico populations studied; however, BS13 by Mexican germplasm combinations seemed to be more promising than Lancaster Composite by Mexican combinations. Because BS13 and Lancaster germplasm exhibit heterosis in crosses, both populations, in combination with Mexican germplasm sources, should be considered for long-term goals. The testcross data suggest sources and combinations of germplasm that can contribute to breeding programs in each country. The BS13 contributed greater yield to testcrosses in Mexico than Lancaster Composite, and some of the improved Mexican populations contributed to the yield of BS13 and Lancaster Composite in the U.S. Corn Belt. Poza Rica 7822 had good combining ability with BS13 and Lancaster Composite. Across 7832 enhanced the yield of BS13 but not Lancaster Composite, whereas Across 7642 enhanced the yield of Lancaster Composite but not BS13 (Table 1). Continued evaluation of elite sources of germplasm from the respective countries will identify sources that can contribute to their respective breeding programs.

REFERENCES

Brown, W.L. 1975. Broader germplasm base in corn and sorghum. Proc. Annu. Corn Sorghum Res. Conf. 30:81–89.

Bruce, G., and E.W. Lindstrom. 1954. A study of the combining abilities of corn inbreds having varying proportions of Corn Belt and non-Corn Belt germplasm. Agron. J. 46:545–552.

CIMMYT. 1982. CIMMYT's maize program: An overview. International Maize and Wheat Improvement Center, El Batan, Mexico.

Clucas, C.P. 1984. Effects of visual selection among and within S_1 lines of maize on S_2 line and testcross performance. Ph.D. diss. Iowa State Univ. Ames (Diss. Abstr. Int. no. 8423696).

Duvick, D.N. 1977. Genetic rates of gain in hybrid maize yields during the past 40 years. Maydica 22:187–196.

Efron, Y., and H.L. Everett. 1969. Evaluation of exotic germplasm for corn hybrids in northern United States. Crop Sci. 9:44–47.
Hallauer, A.R., and O.S. Smith. 1979. Registration of BS13(S2)C1 and BS16 maize germplasm. Crop Sci. 19:755.
Kramer, H.H., and A.J. Ullstrup. 1959. Preliminary evaluation of exotic maize germplasm. Agron. J. 51:687–689.
Lonnquist, J.H. 1974. Considerations and experiences with recombinations of exotic and Corn Belt germplasms. Proc. Annu. Corn Sorghum Res. Conf. 29: 102–117.
Moll, R.H., J.H. Lonnquist, F.J. Velez, and E.C. Johnson. 1965. The relationship of heterosis and genetic divergence in maize. Genetics 52:139–144.
----, W.S. Salhuana, and H.F. Robinson. 1962. Heterosis and genetic diversity in variety crosses of maize. Crop Sci. 2:197–198.
Oyervides-Garcia, M., A.R. Hallauer, and H. Cortez-Mendoza. 1985. Evaluations of improved maize populations in Mexico and the U.S. Corn Belt. Crop Sci. 25:115–120.
Paliwal, R.L., and E.W. Sprague. 1981. Improving adaptation and yield dependability in maize in the developing world. International Maize and Wheat Improvement Center, El Batan, Mexico.
Russell, W.A. 1974. Comparative performance for maize hybrids representing different eras of maize breeding. Proc. Annu. Corn Sorghum Res. Conf. 29:81–101.
Wellhausen, E.J. 1965. Exotic germplasm for improvement of Corn Belt maize. Proc. Annu. Hybrid Corn Ind. Res. Conf. 20:31–44.

Sugar Accumulation in Shrunken-2 Sweet Corn Kernels[1]

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ABSTRACT

Sweet corn (*Zea mays* L.) quality is judged in part by the sugar concentration of its kernels at fresh harvest. Genotypes promoting high kernel sugar throughout the fresh harvest period may improve sweet corn quality and consumer acceptance. This study was undertaken to determine the influence of environment, harvest date, and inbred parent on kernel sugars of shrunken-2 (*SuSu sh2sh2*) sweet corn hybrids. Ten hybrids from a diallel cross of five shrunken-2 sweet corn inbreds were assayed for reducing sugar, sucrose, and total sugar as proportion of kernel dry weight. Kernels were sampled at three fresh harvest dates in 3 yrs. Warmer seasons resulted in lower reducing sugar and higher sucrose at Harvests 1 and 2 (200 and 245 thermal units after pollination, base 10 °C), while cooler seasons were associated with higher reducing sugar and lower sucrose. At Harvest 3 (290 thermal units after pollination), reducing sugar was near 45 g kg^{-1}, and sucrose was near 325 g kg^{-1} in all years. Compensation by these two carbohydrates at Harvests 1 and 2 led to uniformity in total sugar among years. Total sugar was near 430 g kg^{-1} at Harvest 1, 415 g kg^{-1} at Harvest 2, and decreased to near 370 g kg^{-1} at Harvest 3. Hybrid differences were detected for sucrose and total sugar, but not for reducing sugar. The predominance of specific combining ability (SCA) and SCA × harvest effects on sucrose indicate that the concentration and pattern of sucrose accumulation in each hybrid depended upon the combination of inbreds involved in the cross. In addition to SCA and SCA × harvest effects, total sugar was also influenced by general combining ability (GCA) effects; hybrids sharing a common inbred had similar levels of total sugar accumulation. Kernel sugar was high in these shrunken-2 sweet corn hybrids relative to standard sugary (*susu Sh2Sh2*) sweet corn hybrids. Sugar concentration at any one harvest was not as useful for selection among these hybrids as stability of sugar concentration throughout the fresh harvest period. Two hybrids were found not to change significantly in total sugar during the harvest period. One inbred generally promoted stability in kernel sugar across harvests in its crosses.

Additional index words: ***Zea mays*** **L., Maize, Kernel carbohydrates, Diallel analysis.**

Sweet corn (*Zea mays* L.) quality is judged in part by the concentration of non-structural kernel carbohydrates (3,8). These carbohydrates include reducing sugars (glucose and fructose), sucrose, water soluble polysaccharides, and starch (4,6,11). Genotypes that promote higher or more stable sugar concentration during the fresh harvest period contribute to improved sweet corn quality and consumer acceptance.

The shrunken-2 (*SuSu sh2sh2*) genotype is associated with higher kernel sugar and lower kernel starch at fresh harvest, and slower rate of sugar loss after harvest than the standard sugary (*susu Sh2Sh2*) genotype (5). Laughnan (9) reported that 200 g kg^{-1} of shrunken-2 kernel dry weight at maturity was sugar, mostly sucrose. Soberalske and Andrew (13) found shrunken-2 inbreds to have the highest sugar and longest retention of high sugar concentration during the fresh harvest period in a comparison with several endosperm mutants. Whistler et al. (16) determined that kernel sugar in shrunken-2 lines continued to increase longer through kernel maturation than in other endosperm mutant lines.

Significant general combining ability (GCA) effects among sugary and shrunken-2 lines at fresh harvest have been reported for kernel carbohydrates and processing quality, respectively (1,12). Interaction between endosperm mutants and the inbreds into which they were backcrossed suggested that the combining ability effects of shrunken-2 inbreds may not reflect those of the sugary inbreds from which they were derived (13). Environmental conditions also affect kernel quality. High temperatures and excessive rainfall have been associated with lower sugar concentration (10,15) and lower taste panel preference (2).

Our objectives were to determine the effect of three environments, three fresh harvest dates, and five inbred lines on kernel reducing sugar, sucrose, and total sugar of 10 shrunken-2 sweet corn hybrids. We also sought to identify hybrids that maintained high kernel sugar concentration across years and harvests, and inbreds that consistently produced hybrids with these attributes.

MATERIALS AND METHODS

Ten shrunken-2 sweet corn hybrids were developed by a diallel cross of five inbred lines. The inbred lines were

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