Comparison of Two Breeding Methods in Corn I. Effect of Breeding Method on Combining Ability of Third-Cycle Lines[1]

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ABSTRACT

In a search for more accurate methods of genotype evaluation, two different selection methods were evaluated. The objective of this study was to determine the effects of the S_c progeny and testcross methods on general combining ability (GCA) and specific combining ability (SCA) of derived populations and lines. To compare the two methods, one hundred F1 hybrids among twenty selected third-cycle lines (five from each population and method) were tested at two location. There was significant variation within methods in GCA effects among parents for all traits. As a result, a few lines from the S_2 progeny method had combining ability as good as the best lines from the inbred tested method. Breeding method did not appear to influence SCA effects of yield trait. The inbred tested method had a significant 3% yield advantage for all crosses and a 7% gain when only the 50 within-method crosses were considered. These results indicate that the testcross method appears to be more effective for combining ability (grain yield) than the S_2 selection method.

COMPENDIO

Con el objeto de encontrar métodos eficientes para la evaluación de genotipos se evaluaron dos métodos diferentes de selección. El objetivo de este estudio fue determinar el efecto de los métodos, progenie autofecundada y cruce de prueba, sobre la habilidad combinatoria general y la habilidad combinatoria específica de poblaciones y líneas mejoradas. Para comparar los dos métodos, fueron probados en dos localidades 100 híbridos F1 procedentes de veinte líneas seleccionadas en el tercer ciclo (cinco de cada población y método). Hubo una variación significativa dentro de métodos sobre la habilidad combinatoria general entre los diferentes progenitores para todos los caracteres estudiados. Como resultado, unas pocas líneas del método progenie autofecundada mostraron habilidad combinatoria tan buena como las mejores líneas del método cruce de prueba. La respuesta de los dos métodos sobre la habilidad combinatoria específica no parece tener influencia en el rendimiento. El método cruce de prueba mostró un incremento en el rendimiento del 3% en todos los cruces y un 7% de ganancia cuando solamente 50 cruces dentro de cada método fueron considerados. Esos resultados indican que el método cruce de prueba parece ser más efectivo para detectar habilidad combinatoria (rendimiento de grano) que el método de selección S_2.

INTRODUCTION

Many different maize breeding methods have been used successfully, but only a few reports have been published in which direct comparisons were made of relative effectiveness with alternative methods (5) Two such methods which have been of particular interest to this study are the selfed progeny method using S_2 lines and the testcross progeny method using an inbred tester

Until the 1970s it was usually accepted that use of an inbred line would improve combining ability with the specific tester but would have little value for the improvement of general combining ability (10) However, the significance of the findings (4, 7, 9) showed that such testers are effective for improving general as well as specific combining ability (SCA)

On the basis of results by Darrah *et al.* (3) and Horner *et al.* (4), showing that genetic variance among testcross progenies using inbred testers was about twice as large as when broad-base testers were used, Russell and Eberthart (8) proposed a modified reciprocal recurrent selection scheme using inbred testers of the populations themselves as a means of utilizing additive genetic variance However, Comstock (2) indicated that in theory the populations are expected to be slightly superior to inbred lines as testers for changing allele frequency, even though the latter result in larger genetic variance among progenies

In a later experiment, Jensen *et al.* (6) reported that testcrosses are superior to S_2 tests when selecting for combining ability They suggested that most of exploitable genetic variation in their elite materials was probably nonadditive

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After three cycles, however, Horner (5) again, as in the first cycle, found no significant difference between S_2 and testcross methods for combining ability improvement. Nevertheless, S_2 selection resulted in a markedly better yield of inbred lines than the testcross method. He suggested that genetic variation for yield in corn is largely additive. However, some nonadditive variation in the overdominance range at some loci is possible

MATERIALS AND METHODS

Twenty selected third-cycle lines (five from each population and method), were grown at the University of Florida in Gainesville during 1985 in adequate quantities to make intercrosses in a factorial mating design. Lines with an "S" in the name were from the S_2 progeny method and those with a "T" were from the testcross method. Each of the 10 parental strains (3AS and 3AT) in Population A was crossed to each of the 10 parents (3BS and 3BT) in Population B. This resulted in 100 crosses, excluding reciprocals. Making the crosses involved collecting pollen from eight to 12 plants of each parent from Population A and bulking the pollen before applying it to eight to 12 plants of each of the 10 parents in Population B. Pollen from plants of parents in Population B was handled likewise. After harvest and drying, the ears from each cross were shelled and the seed was bulked to produce one seed lot for each cross.

The 100 crosses were tested in one-row plots at two locations with different soil types near Gainesville, Florida, in 1986, using a randomized complete block design (RCBD) with nine replications at each location. Row spacing was 91 cm and the plants were spaced 30.5 cm apart in the rows. Two seeds were planted per hill and the plants were thinned to one per hill at the seedling stage. After thinning, there was a maximum of 20 plants per plot at both locations. A purple stalk hybrid was used for border rows. Fertilization was according to recommended rates for the area. Weeds were controlled with a preplant incorporated application of atrazine and Sutan plus, as well as some cultivation. Irrigation and insecticides were applied when required for proper growth.

Table 1. Combined analyses of variance for grain yield, ear height, number of two-eared plants, percentage erect plants, and husk score at two locations.

Source of variation	df	Grain yield£ Mg/ha	Ear height& cm	Two-eared plant no.	Erect plant# %	Husk+ score
Locations (L)	1	244.55**	6 598.2**	4 439.4**	447 966.7**	12.8**
Reps/L	16	34.70**	212.1**	51.4**	2 091.9**	9.2**
Crosses (C)	99	4.83**	26.0**	183.6**	3 214.9**	29.9**
A parent crosses	9	25.89**	71.1**	994.7**	5 887.6**	179.7**
Methods (M)	1	30.04**	156.1**	7.0	714.3	405.4**
Lines/M	8	25.47**	60.5**	1 118.2**	6 534.3**	151.5**
B parent crosses	9	8.14**	164.4**	684.6**	25 088.0**	79.4**
Methods (M)	1	9.75*	331.3**	352.6**	22 302.6**	54.4**
Lines/M	8	7.90**	143.5**	726.1**	25 436.2**	82.5**
A x B	81	2.12**	5.7	37.8**	487.6**	7.8**
C x L	99	1.44**	6.9*	18.5**	2 328.2**	2.3**
A x L	9	2.17**	9.4	65.4**	4 294.5**	5.4**
B x L	9	4.06**	17.2**	81.6**	19 781.2**	6.1**
(A x B) x L	81	0.71	5.4	6.3	170.5	1.5
Error	1 584	0.76	5.1	6.0	213.5	1.3

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

+ Scores were on a 1 (good) to 9 (poor) scale.

£ Shelled grain at 15% H_2O in Mg ha^{-1}

& Measured in cm to the node of top ear attachment

Percentage of plants with stalks not broken below the ear at harvest.

Data were recorded for grain yield per plot, average ear height, percentage two-eared plants, mean husk score, percentage erect plants at harvest, and ear (grain) quality A one-row plot combine was used for harvest, with are care taken to pick up lodged plants. Yield was measured in megagrams of grain per hectare adjusted to 15% moisture before analysis.

To estimate General Combining Ability (GCA) and Specific Combining Ability (SCA) effects, the crosses' sums of squares were partitioned into sources of variation due to crosses of the 10 A parents, the 10 B parents, and A x B interaction. The crosses' (C) and locations' (L) sums of squares were similarly partitioned into A x L, B x L, and (A x B) x L sources (Table 1)

RESULTS

Variation among the 100 crosses was significant ($P < 0.01$) for all traits studied (Table 1) Interaction between crosses and locations was also significant at the 0.01 level for all traits except ear height, which showed significance only at the 0.05 level Variation for general combining ability (GCA) among parents was significant ($P < 0.01$) in both populations for all traits Except for ear height in Population A, GCA x location interactions were also significant ($P < 0.01$) for all traits

In parental Group A the inbred tester method was superior ($P = 0.01$), on the basis of all crosses, to the S_2 progeny method for grain yield, ear height, and husk score. Mean differences for these traits were, respectively, 0.26 Mg/ha (4%), 3.6 cm (3%), and 1.0 (19%) In Parental Group B, the inbred tester method was superior at the 0.05 level for grain yield (0.14 Mg/ha or 2%) and at the 0.01 level for ear height (4%), two-eared plants (15%), erect plants (9%), and husk score (7%) (Tables 1 and 2) On the basis of means within methods of the 25 crosses obtained by crossing, the 3AS with the 3BS lines, compared with the 25 3AT by 3BT crosses, the inbred tester method was superior by an even larger margin for all traits (Table 2, last column).

Specific combining ability (SCA) effects (A x B interaction) were significant at the 0.01 level for all traits except ear height (Table 1). These results show that some crosses performed significantly better or worse than expected, based on the GCA values of their parents No significant difference was detected for interaction of SCA effects with locations

There was significant ($P < 0.01$) variation within methods in GCA among parents in both parental groups for all traits As a result, a few lines from the S_e progeny method had combining ability (CGA) as good as the best lines from the inbred tester method (Table 3) For example, line 3AS2 had high GCA values for grain yield

The average performance of a line in a series of crosses is a measure of its GCA, whereas the performance of a specific cross in relation to expected performance based on parental GCA measures the SGA of the two lines being crossed. The results of grain yield (Table 3) show that 3AS2, 3AT15, 2AT98-2-1, and 3AT10 in parental group A were good general combiners for grain yield The rest of the parents except 3AT3 showed negative GCA effects, which suggests that they were below average for this group of parents. The range in GCA effects for the A Group was from -0.46 to +0.64 ± 0.26 Mg/ha. In the B Parental Group, 2BT40 and 3BT2 were good general combiners, and 3BS1, 3BT1, and 3BT8 were very close to the average. The range in GCA effects for the B Group was from -0.37 to +0.28 ± 0.26 Mg/ha These data also suggest that the inbred tester method was more effective than the S_2 progeny method for evaluating GCA because more "T" than "S" lines were high in GCA

On the basis of standard deviations of SCA effects for the 25 crosses obtained by crossing the 3AS with the 3BS lines versus the 25 3AT by 3BT crosses, no significant difference was found between the S_2 progeny method and the testcross method Thus, breeding method did not appear to influence SCA effects on yield trait

DISCUSSION

The results reported in this experiment have shown that the testcross method gave significantly better progress for combining ability in yield than the S_2 progeny method. Nevertheless, a few lines from the S_e progeny method had GCA as good as the best lines from the inbred tester method.

Similar results reported by Horner *et al* (4) showed that use of the inbred line F6 as the tester resulted in about twice as much improvement in GCA during five cycles of selection as use of the parental population as the tester or the S_2 progeny method Baniya (1), using a different base population, reported after two cycles of selection that both methods were effective in improving combining ability; the inbred tester method was significantly superior to the S_2 progeny method in Population A, based on crosses with both the inbred and population testers. Jensen *et al* (6) found with elite materials that eval-

Table 2. Comparison of two selection methods for performance of crosses between selected inbred lines in two populations.

	Population A			Population B				
Method of selection	Gainesville	Green Acres	Average	Gainesville	Green Acres	Average	Mean for all crosses	Mean within+ methods
	Grain yield, Mg/ha			Grain yield, Mg/ha				
S_2 progeny	5.81	6.55	6.18	5.87	6.60	6.24	6.21	6.15
Inbred tester	6.07	6.81	6.44	6.01	6.76	6.38	6.41	6.56
			**			*		
	Ear height, cm			Ear height, cm				
S_2 progeny	108.7	129.3	119.0	109.2	129.5	119.4	119.2	121.7
Inbred tester	104.7	126.1	115.4	104.3	125.9	115.1	115.2	113.7
			**			**		
	Two-eared plants			Two-eared plants				
S_2 progeny	4.2	7.2	5.7	3.8	6.5	5.2	5.4	5.4
Inbred tester	3.9	7.2	5.6	4.2	7.8	6.0	5.8	6.1
			ns			**		
	Erect plants, %			Erect plants, %				
S_2 progeny	95.2	62.4	78.8	95.4	56.5	76.0	77.4	75.7
Inbred tester	95.1	65.1	80.1	95.0	71.0	83.0	82.0	84.1
			ns			**		
	Husk score			Husk score				
S_c progeny	6.4	6.4	6.4	6.1	6.2	6.2	6.3	6.5
Inbred tester	5.3	5.6	5.4	5.6	5.9	5.8	5.6	5.2
			**			**		

*, ** Means within columns in a group are significantly different at the 0.05 and 0.01 levels, respectively.
\+ Means of the 25 crosses AS x BS versus means of the AT x BT lines
ns nonsignificant.

uation of S_2 lines by the testcross method increases hybrid yields by 6%, compared with only 1% S_2 per evaluation. They concluded that the exploitable genetic variation in their elite germplasm was largely non-additive. Horner (5) obtained no significant difference between methods for combining ability improvement, however, in a separate study of the same material used here. His study also showed that significant progress had been made with both methods. It was possible in the experiment reported on here to make a more precise comparison of the third-cycle populations than was done in the study reported on by Horner (5). The factorial mating design produced a larger number of crosses for testing; populations from earlier cycles were not included; and more replications were used. The inbred tester method resulted in a 1% grain yield advantage (non-significant) over the S_2 progeny method after three cycles in the earlier experiment; in this experiment, the inbred tester method had a significant 3% yield advantage for all crosses and a 7% advantage when only the 50 within-method crosses (A x B) are considered.

If the objective of breeding is to improve combining ability (grain yield), the inbred tester method appears to be more effective than the S_2 progeny.

Table 3. GCA and SCA effects of the 100 crosses relative to the mean grain yield. The upper number is the mean for the cross and the lower is the SCA effect.

	SCA effects (Mg/ha											
Parents	3BS1	3BS2	3BS5	3BS6	3BS7	2BT40	3BT1	3BT2	3BT5	3BT8	Standard deviation of SCA effects	GCA effects (Mg/ha)
3AS2	7.05	6.42	6.93	7.21	7.40	7.44	6.70	7.13	6.19	7.08		
	+0.040	−0.149	+0.069	+0.143	+0.498	+0.428	−0.295	−0.104	−0.475	+0.021	0.28	+0.64
3AS3	6.10	5.64	5.64	5.92	6.18	5.95	6.07	6.26	5.48	5.53		
	+0.168	+0.149	−0.143	−0.069	+0.356	−0.164	+0.153	+0.104	−0.107	−0.451	0.23	−0.43
3AS6	6.36	5.46	6.29	6.39	5.76	5.75	5.94	6.74	5.99	6.15		
	+0.222	−0.237	+0.301	+0.195	−0.270	−0.570	−0.183	+0.378	+0.197	−0.037	0.31	−0.23
3AS12	5.78	5.46	5.80	6.58	5.76	5.22	6.59	6.10	5.32	5.86		
	−0.122	+0.001	+0.047	+0.621	−0.034	−0.864	+0.703	−0.026	−0.237	−0.091	0.44	−0.46
3AS15	6.33	5.66	5.96	5.92	5.88	6.16	6.82	6.28	5.90	6.58		
	+0.126	−0.103	−0.095	−0.341	−0.216	−0.226	+0.631	−0.148	+0.041	+0.327	0.29	−0.16
3AT3	6.96	5.98	5.74	6.37	6.34	6.66	6.29	6.74	6.00	6.45		
	+0.552	−0.013	−0.519	−0.095	+0.040	+0.070	−0.103	+0.108	−0.063	−0.007	0.26	+0.04
3AT6	6.08	5.51	5.87	6.16	5.54	6.72	6.14	6.10	5.38	6.38		
	+0.037	−0.092	−0.024	+0.060	−0.395	+0.495	+0.112	−0.167	−0.318	+0.288	0.27	−0.32
3AT15	6.28	6.40	6.64	6.96	6.68	6.96	6.42	7.00	6.44	6.46		
	−0.396	+0.165	+0.113	+0.227	+0.112	+0.102	−0.241	+0.101	+0.109	−0.265	0.21	+0.31
2AT98-2−1	5.96	6.55	6.78	6.26	6.35	7.53	6.50	7.06	6.43	7.42		
	−0.779	+0.252	+0.190	−0.536	−0.281	+0.609	−0.224	+0.097	+0.036	+0.632	0.46	+0.37
3AT10	6.76	6.17	6.52	6.46	6.69	7.09	6.04	6.49	7.08	6.24		
	+0.151	+0.002	0.060	−0.206	+0.189	+0.299	−0.554	−0.343	+0.816	−0.418	0.40	+0.24
Standard deviation of SCA effects	0.37	0.15	0.22	0.33	0.29	0.46	0.40	0.20	0.35	0.34		
GCA effects	+0.06	−0.37	−0.09	+0.11	−0.05	+0.24	+0.04	+0.28	−0.29	+0.10		

S.E. GCA = 0.26 Mg/ha
S.E. SCA = 0.78 mg/ha

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Comparison of Two Breeding Methods in Corn II. Determination of Inbreeding Depression[1]

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ABSTRACT

Examination of inbreeding and its effects contributing to genetic variation among the selfed progenies involved should help point up the changes that would occur in the selfing lines, and should be very helpful to predict progress with each of the two methods (S_2^2 progeny and testcross). To compare the two methods, bulked populations of the Syn-1, S_1, and S_2 generations from intercrosses among selected cycle-three lines from each population and method were tested at two locations for two years. The S_2 progeny method resulted in significantly less inbreeding depression than the testcross method for grain yield of cycle-three populations, producing more vigorous lines in the S_1 and S_2 generations, whereas in the Syn-1 generation there was no significant difference between the two methods. The results suggest the possibility that both methods emphasize different types of gene action.

COMPENDIO

El examen de endogamia y los efectos que contribuyen a la variación genética entre las progenies autofecundadas involucradas, puede ayudar a delucidar los cambios que ocurren en las líneas autofecundadas; además de predecir progreso con cada uno de los métodos (progenie autofecundada y cruce de prueba). Para comparar los dos métodos, poblaciones masales de tres generaciones (Syn-1, S_1 y S_2), provenientes de cruzamientos entre lineas avanzadas del tercer ciclo de cada población y método, fueron evaluadas en dos localidades durante dos años. El método progenie autofecundada resultó significativamente con menor pérdida de endogamia que el método cruce de prueba para rendimiento de grano, produciendo líneas más vigorosas con los sintéticos S_1 y S_2; mientras que el sintético 1 no mostró diferencia significativa entre métodos. Los resultados sugieren la posibilidad de que ambos métodos de selección enfatizan diferentes tipos de acción génica.

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INTRODUCTION

Inbreeding and its effect on genetic variation among the selected progenies is very helpful for understanding the changes that would occur in the selfing series. Maximum inbreeding is obtained when like gametes, A with A or a with a, unite and under such conditions the inbreeding coeficient (F) will be one because in the gene a particular character