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Developing Hybrids from Two Improved Maize Populations[1]

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Summary. The performance of a group of 49 hybrids from seven elite maize (*Zea mays* L.) lines selected from each of the two populations, BSK(S)C5 and BSSS(R)C5, was compared with the varietal-cross hybrid of the source populations and with elite single-cross hybrids. Both populations had been improved by five cycles of recurrent selection. BSK(S)C5 was improved by S_1 selection from BSK; whereas BSSS(R)C5 was improved by reciprocal recurrent selection from BSSS with BSCB1 as the tester.

The mean yield of all hybrids was statistically higher than the mean yield of the varietal-cross hybrid and approached the yields of the checks, indicating that early testing in phase 1 was effective. Nine hybrids were significantly higher yielding than the varietal cross, and their yields were similar to those of the checks. The best hybrid outyielded the varietal cross by 18%.

The data obtained from this study indicate that improved populations developed from recurrent selection programs should be useful sources for improved conventional hybrids when the varietal cross yields at least 90% as much as the better current hybrids.

Introduction

Several schemes of recurrent selection have been used to produce improved heterogeneous populations to serve as foundation material for the development of new improved hybrids. In a study of possible ways for commercial utilization of the products of recurrent selection, Horner *et al.* (1972) reported that commercial maize (*Zea mays* L.) hybrids could be generated rapidly from a program of recurrent selection for specific combining ability when the tester was a seed parent already in commercial use. As a result of their study, a topcross hybrid, Florida 200A, was released in 1965 for commercial production in north and west Florida (Horner *et al.*, 1965).

Hallauer (1973) used reciprocal full-sib selection to improve two populations and to develop hybrids. The populations, 'Iowa Two-ear Synthetic' (BSTE) and 'Pioneer Two-ear Composite' (PRC), had low frequencies of two ears per plant at moderate plant densities. After one cycle of selection, BSTE C1 showed 14% and PRC C1 showed 19% higher yields than the original populations. The improvement in yield for the varietal-cross hybrid after one cycle of selection was about 10%. Full-sib progenies (cryptic double crosses equivalent to $S_1 \times S_1$ crosses) developed from the C1 populations also yielded more than the full-sib progenies from the CO populations. Forty-six percent of the C1 full-sib progenies ($S_0 \times S_0$ crosses) exceeded the mean of the checks, and 16% exceeded the mean of the checks by one or more standard errors. In contrast, only 1% of $S_0 \times S_0$ crosses from the original populations exceeded the mean of the same six checks, and none was more than one standard error above the mean.

The purpose of this study was to evaluate an alternative method of developing superior hybrids from improved maize populations. Efficient development of hybrids from varieties under population improvement has three phases:

1. Early testing provided by selection trials for the next cycle of recurrent selection.
2. Preliminary evaluation of hybrids using early-generation lines to identify superior combinations.
3. Final evaluation of advanced-generation lines in the superior hybrid combinations as identified in phase 2.

This study was designed to provide information on phases 1 and 2 only.

Materials and Methods

Hybrids of early generation lines from two improved populations, BSK(S)C5 and BSSS(R)C5, and the varietal cross of these populations were used in this study. BSK(S)C5 was developed from 'BSK' (Krug Hi I Syn.-3) and BSSS(R)C5 was developed from 'BSSS' (Iowa Stiff Stalk Synthetic) by recurrent selection. Progress in improving the populations was reported by Burton *et al.* (1971) and Penny and Eberhart (1971).

In 1966, the 10 lines selected from BSK(S)C4 were recombined by making all 45 combinations of the diallel cross. In 1967, the 45 crosses of BSK(S)C5 were grown in single-row plots of 25 plants each. Within each plot several plants were selfed and at harvest the two or three best plants were saved. One hundred S_1 lines were grown

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in yield trials in 1968, and the 10 lines having the highest yields were saved. Seven of these were selected for this study: 04—2, 06—1, 11—1, 33—1, 34—2, 35—2, and 40—1.

In 1968, approximately 300 plants of BSSS(R)C5 were grown and selected plants were selfed. At harvest, ears from 173 plants were saved and grown as S_1 lines in single-row plots of 17 plants in the 1969 nursery. One hundred lines with the lowest ratings for corn borer leaf feeding were selected for selfing and for crossing to BSCB1(R)C5 in the reciprocal recurrent selection program. One plant within each selected S_1 line was selected at pollinating time for low ear height, vigor, and simultaneous silking of the top ear shoots. Eleven of the 100 S_2 lines were chosen for their agronomic characteristics in Corn Borer and Breeding nurseries in 1969. Four lines were discarded later because of poor topcross yields with the BSCB1(R)C5 tester. Lines 052—1, 067—1, 076—1, 082—2, 093—1, 114—1, and 132—1 were used in this study.

Hybrids were formed between the seven lines from BSK(S)C5 and the seven lines from BSSS(R)C5 to give 49 hybrids. These 49 hybrids plus four samples of the varietal cross (BSK(S)C5 × BSSS(R)C5) and three single-cross hybrids (B14A × B45, B37 × B45, and B37 × × OH43) were grown in a 56-entry experiment at each of four locations in Iowa in 1971. The experimental design was a 7×8 simple (2 replications) rectangular lattice of two-row plots (36, 36, 38, and 38 seeds planted per plot). Plant densities were equivalent to 49,100, 49,100, 40,800, and 38,600 plants/ha for the four locations.

Plant heights (cm from ground to the collar of the flag leaf) and ear heights (cm from the ground to the top ear node) were recorded on the first 10 competitive plants in each plot. Stalk lodging was expressed as percentage of the stalks broken below the ear. At two locations plots were hand harvested, but at the other two they were machine harvested. Plot harvest weights were converted to q/ha of shelled corn at 15.5% grain moisture. Covariance was used to adjust yields to a uniform stand within each location.

Results

The combined analyses of variance of five characters from the four locations are given in Table 1. The mean yield of hybrids was higher than that of the varietal cross by 4.3 q/ha or 6.3% (Tables 1 and 2).

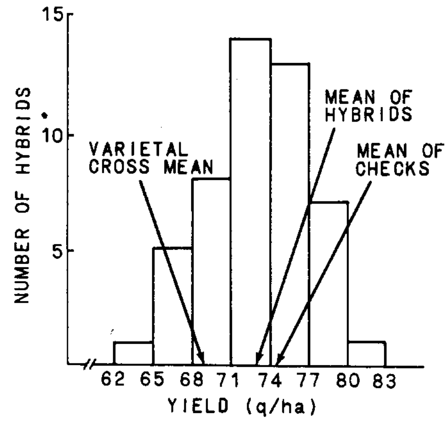

Fig. 1. Distribution of 49 hybrids, their mean, the varietal-cross mean, and the mean of the three checks grown at four locations in Iowa in 1971

The yields of nine of the 49 experimental hybrids were significantly higher than the yield of the varietal cross (Tables 2 and 3; Fig. 1). The two most productive hybrids outyielded the varietal cross by 12.6 q/ha (18.3%) and 10.6 q/ha (15.4%).

Grain moisture percentage for all hybrids (Table 2) was higher than that for the varietal cross. Seven of the nine highest-yielding hybrids were significantly higher in grain moisture than the varietal cross. For both populations, the variation among hybrids resulted from differences in moisture among the lines (Tables 4 and 5) and in the interaction (Table 1).

Mean stalk lodging for all crosses was significantly higher than that for the checks (Table 2), and hybrids differed significantly for this trait. There were significant differences for stalk lodging among lines within both BSK(S)C5 and BSSS(R)C5 (Tables 4 and 5), but there was no interaction (Table 1). Only one hybrid, BSK(S)C5 11—1 × BSSS(R)C5 067—1 (Table 2), was significantly higher in stalk lodging percentage

Table 1. *Mean squares from combined analyses of variance for five characters measured on corn hybrids at four locations in Iowa in 1971*

Source	d. f.[a]	Mean squares				
		Yield	Grain moisture	Stalk lodging	Plant height	Ear height
Entries	55	139.0†	16.43**	583.8**	241.4**	214.0**
Hybrids vs. VC	1	546.4*	73.39**	67.4	211.1*	370.1**
Among hybrids	48	135.0	11.32**	595.0**	237.1**	113.2**
BSK(S)C5 lines	6	172.1	7.71**	1119.8**	307.7**	45.0
BSSS(R)C5 lines	6	147.8	60.83**	2412.3**	1133.7**	596.4**
Interaction	36	126.6	3.67*	204.6	75.9	44.0*
Among checks	2	182.0	65.15**	510.4	511.1**	652.3**
Checks vs. hybrids + VC	1	65.8	155.26**	2384.5**	494.9**	4584.4**
Quadruplicate VC	3	62.9	0.50	26.3	56.3	26.5
Location × entries	55 ($p-1$)	104.9 (165)	2.36** (165)	182.5** (110)	47.4* (55)	26.4 (55)
Effective pooled error		83.9 (166)	0.83 (154)	79.6 (143)	27.1 (82)	25.9 (96)

[a] Degrees of freedom are in parentheses when dissimilar among characters.
**, *, † Significant differences at 0.01, 0.05, and 0.10 levels of probability, respectively.

Table 2. *Means of the nine highest yielding hybrids, the varietal cross, and the three checks grown at four locations in Iowa in 1971*

Pedigree		Yield q/ha	Stand %	Grain moisture %	Stalk lodging %	Plant height cm	Ear height cm
BSK(S)C5 × BSSS(R)C5							
35−2	052−1	81.4**	83.2**	20.4	14.7	236	123
11−1	067−1	79.4**	92.0	20.8	40.7*	256**	127
34−2	093−1	79.1*	89.9	21.3*	13.1*	243	128
34−2	132−1	78.8*	96.4	23.6**	30.0	236	133**
40−1	052−1	78.7*	83.6**	21.2*	16.7	236	119
11−1	076−1	78.6*	96.0	21.5**	23.7	261**	138**
11−1	052−1	78.3*	89.4	22.1**	29.4	240	125
06−1	082−2	77.2*	88.6	22.2**	35.1	252**	134**
04−2	052−1	76.9*	95.0	22.6**	11.6*	238	127
Mean (9 elite hybrids)		78.7	90.5	21.7	23.9	244	128
Mean (All hybrids)		73.1	89.1	21.5	24.0	243	128
Varietal-cross mean		68.8	91.4	19.9	25.8	240	123
Checks	B14A × B45	74.0	91.3	16.0	10.6	245	118
	B37 × B45	79.5	93.3	18.6	22.3	241	112
	B37 × OH43	70.0	89.7	21.7	4.1	224	93
Mean (All checks)		74.5	91.4	18.8	12.3	237	108
L.S.D. (.05)		10.2	7.1	1.5	15.6	10	7

**, * Significant differences from the varietal-cross mean at 0.01, and 0.05 levels of probability, respectively.

Table 3. *Grain yields, q/ha, of the 49 hybrids grown at four locations in Iowa in 1971*

	BSSS(R)C5							Mean
	052−1	132−1	067−1	093−1	076−1	114−1	082−2	
BSK(S)C5								
34−2	76.1	78.8	75.6	79.1	71.5	73.9	73.2	75.5
11−1	78.3	76.2	79.4	73.5	78.6	73.3	65.6	75.0
35−2	81.4	72.7	74.8	76.7	67.7	71.3	72.5	73.9
06−1	71.2	71.4	71.1	70.2	76.6	74.5	77.2	73.2
04−2	76.9	76.3	71.0	69.7	75.8	70.8	63.1	71.9
33−1	69.6	69.2	74.9	71.7	71.7	68.5	75.5	71.6
40−1	78.7	69.5	66.7	72.4	66.3	75.5	66.8	70.8
Mean	76.0	73.4	73.4	73.3	72.6	72.5	70.6	73.1

Table 4. *Summary of agronomic data obtained on seven selected S_1 lines from BSK(S)C5 grown in 1968, and agronomic data obtained as line means from hybrids with seven BSSS(R)C5 S_2 lines grown in 1971*

BSK(S)C5 Lines	Yield (q/ha)		Grain moisture (%)		Stalk lodging (%)		Plant ht. (cm)	Ear ht. (cm)
	S_1	Hybrids with BSSS(R)	S_1	Hybrids with BSSS(R)	S_1	Hybrids with BSSS(R)	Hybrids with BSSS(R)	Hybrids with BSSS(R)
34−2	55.5	75.5	21.7	21.2	8.8	15.4	242	130
11−1	56.3	75.0	21.8	21.7	50.8	31.2	247	127
35−2	55.4	73.9	19.4	21.0	34.9	24.0	238	127
06−1	55.8	73.2	22.5	21.6	39.4	28.8	245	127
04−2	55.8	71.9	23.9	21.8	36.8	22.6	245	128
33−1	56.8	71.6	22.8	22.0	34.9	25.0	242	128
40−1	59.3	70.8	23.2	21.2	29.7	21.1	246	129
Mean	56.4	73.1	22.2	21.5	33.6	24.0	243	128
LSD (.05)	6.2	n. s.	1.4	0.6	13.3	5.8	4	3

Table 5. *Summary of agronomic data obtained on seven selected S_2 lines from BSSS(R)C5 crossed to BSCB1(R)C5 and grown in 1970, and agronomic data obtained as line means from hybrids with seven BSK(S)C5 S_1 lines grown in 1971*

BSSS(R)C5 Lines	Yield (q/ha)		Grain moisture (%)		Stalk lodging (%)		Plant ht. (cm)	Ear ht. (cm)
	Hybrids with BSCB1(R)	Hybrids with BSK(S)	Hybrids with BSCB1(R)	Hybrids with BSK(S)	Hybrids with BSCB1(R)	Hybrids with BSK(S)	Hybrids with BSK(S)	Hybrids with BSK(S)
052—1	68.7	76.0	21.8	21.4	10.0	20.5	237	123
132—1	71.8	73.4	25.4	22.8	17.2	37.1	236	126
067—1	70.0	73.4	23.5	20.5	9.8	30.1	250	128
093—1	79.2	73.3	23.1	22.6	9.2	18.9	245	122
076—1	70.0	72.6	21.4	20.6	5.9	17.2	252	134
114—1	72.6	72.5	24.0	20.4	4.1	17.5	245	133
082—2	80.2	70.6	25.1	22.3	5.2	26.9	240	130
Mean	73.2	73.1	23.5	21.5	8.8	24.0	243	128
LSD (.05)	8.6	n. s.	1.7	0.6	7.7	5.8	4	3

P = .05) than the varietal cross. Hybrids of BSK(S)C5 11—1 and BSSS(R)C5 067—1 were high in stalk lodging percentages, and hybrids of BSK(S)C5 34—2 and BSSS(R)C5 076—1, 114—1, and 093—1 were low. Two hybrids, BSK(S)C5 34—2 × BSSS(R) C5 093—1 and BSK(S)C5 04—2 × BSSS(R)C5 052—1, were significantly lower in stalk lodging than the varietal cross.

Differences in plant and ear heights were significant among checks and among hybrids (Table 1). The means of hybrids were slightly, but significantly, higher than the varietal-cross mean for plant and ear heights (Table 2). Variation in plant height among hybrids was related to the differences that existed among lines in the BSK(S)C5 (Table 4) and BSSS(R)C5 (Table 5) populations. Three of the nine highest yielding hybrids were significantly taller than the varietal cross (Table 2). For ear height, the variation among BSSS(R)C5 lines and the interaction among lines of the two populations contributed to the differences among hybrids. Ear height of three of the hybrids listed in Table 2 was greater than that of the varietal cross, and ear height of the nine hybrids and the varietal cross was considerably greater than that of the three checks. Both ear height and plant height of hybrids 11—1 × 076—1 and 06—1 × 082—2 were greater than those of the varietal cross.

Discussion

Our results indicate that superior hybrids can be developed from the maize populations BSK(S)C5 and BSSS(R)C5. Furthermore, the testing to select lines for recurrent selection in these populations also provided early testing for general combining ability (phase 1) to identify the elite S_1 and S_2 lines.

The mean yield of 49 hybrids exceeded the BSK-(S)C5 × BSSS(R)C5 varietal-cross mean by 6%; whereas, the mean of hybrids from unselected lines would be expected to be equal that of the varietal-cross mean. Because selected lines were used to make the hybrids, significant variation among the hybrid yields could not be detected with the limited number of replications and locations used in this preliminary study (phase 2). Yields of the best hybrid was 18% higher than that of the varietal cross but similar to that of the best check, B37 × B45.

The covariance analysis reduced the error mean square for yield at most locations because the trials were not over planted and thinned. Although much of the variation in stand seemed to be randomly distributed in the field, genetic differences among hybrids were detected. Thus, part of the yield superiority of 35—2 × 052—1 and 40—1 × 052—1 may have been due to adjustments for differences in stand.

Hybrids from the BSK(S)C5 and BSSS(R)C5 lines differed significantly in stalk lodging. Although the average stalk lodging of the 49 hybrids was high compared with that of the checks, lodging of certain hybrids was verylow. The BSK(S)C5 lines probably were responsible for the excessive lodging. The agronomic characters of the breeding populations, however, can be improved simultaneously with yield in the recurrent selection program as pointed out by Penny and Eberhart (1971) so that most of the lines extracted in phase 2 will be acceptable for important agronomic characters. Furthermore, selection among S_3 or S_4 sublines from elite S_1 lines should give additional improvement. After superior yielding hybrid combinations have been identified, selection for agronomic characters such as lodging, plant and ear heights, corn borer resistance, and *Diplodia* resistance should be practiced among sublines in the inbreeding program before the advanced-generation lines are evaluated as single-cross hybrids in phase 3. Selection in the recurrent selection program as well as during the inbreeding phase should be effective because these characters are highly heritable. Therefore, sublines of BSK(S)C5 35—2, 34—2, 04—2, and 40—1 and sublines of BSSS(R)C5 052—1 and 093—1 should be selected and evaluated in the hybrid combinations — 35—2 × 052—1, 34—2 × 093—1, 40—1 × 052—1, and 04—2 × 052—1 — because these four combinations yielded significantly more than the varietal-cross hybrid and were similar in stalk lodging to the hybrid checks.

All 14 selected lines were inbred another generation while the yield trials were being conducted, but only the sublines of BSK(S)C5 35—2, 34—2, 04—2, and 40—1 and BSSS(R)C5 052—1 and 093—1 should be retained. Because $S_1 \times S_1$ lines are equivalent to double crosses, hybrids from $S_5 \times S_5$ lines will have greater genetic variation than hybrids from $S_1 \times S_1$ lines. Cockerham (1961) has pointed out that the genetic variation among double crosses from unselected homozygous lines is only $(1/2)\ \sigma_A^2 + (1/4)\ \sigma_D^2$, whereas the genetic variation among comparable single crosses is $\sigma_A^2 + \sigma_D^2$. The additional variation among single-cross hybrids of advanced-generation lines will assist in the identification of the superior hybrids in phase 3.

BSK(S)C5 had been under intrapopulation recurrent selection (S_1 selection) and had not been selected for improved combining ability with BSSS, and BSSS(R)C5 had been selected by using reciprocal recurrent selection with BSCB1. The BSK(S) $\times$ $\times$ BSSS(R) hybrids, however, yielded well. The results from the comparison between the varietal-cross hybrid and the elite hybrids of this study agreed with the results of Hallauer (1973). The impressive performance of both types of hybrids in this study may have resulted from the good general combining ability of BSSS(R)C5. BSSS has shown good general combining ability when crossed to several populations, as reported by Hallauer and Sears (1968) and Hallauer (1972). The use of recurrent selection trials as early testing for hybrid development greatly increases the efficiency of a breeding program and should be a much more efficient procedure than inbreeding a large number of lines to homozygosity and then testing in a completely separate hybrid development program as has been done in the past.

A diallel design of varietal crosses should be used to identify varietal-cross combinations that give superior yields of varieties under intrapopulation improvement. This study and the results of Hallauer (1973) suggest that the expected yield superiority of the best hybrid is 18 to 25% over that of the varietal-cross mean. Hence, extensive efforts to develop hybrids of lines selected from varieties cannot be justified unless the varietal cross can yield 90% or more than the best commercial hybrids. Varieties from several population improvement programs, however, are giving varietal crosses or topcrosses that are similar in yield to that of the best commercial hybrids (Darrah *et al.* 1972, Eberhart 1971, Horner *et al.* 1965, Moll and Stuber 1971). These improved populations can be used as sources of elite lines for hybrid development.

As long as the breeding populations are continuously improved by recurrent selection, breeders should be able to extract the best lines from each cycle of selection for the formation of conventional hybrids that are higher yielding than those from the previous cycles. The use of an efficient system, as used in this study, will greatly reduce the cost of hybrid development because selection trials in the population improvement phase can be used as early testing to identify the superior early-generation inbred lines. Furthermore, the periodic release of new hybrids derived from several genetically diverse breeding populations should reverse the trend toward narrowing the genetic base of maize hybrids in commercial use.

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