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Performances of Composite-Sibbed Lines of Corn Derived from Different Selection Methods and Their Hybrid Combinations

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ABSTRACT

Six S_1 populations from six commercial single crosses of corn were used as the starting breeding material, with each selected independently under low plant density conditions (1.5 plant/m^2) by two different methods of selection: 1) selfed family line selection (SFL); and 2) recurrent S_1-full sib line selection (RFL). Breeding was carried out for three generations and the top six lines of each method were selected. Afterward, lines from the second method were separated into 18 sublines and each was subjected to RFL and MSL (mass sibbed line selection) for another three generations. Consequently, the best six lines from each selection method were subjected to further selection by the method from which each line was derived, but under high (5.3 plant/m^2) and low (1.5 plant/m^2) plant density conditions. There was no clear advantage in crosses of lines selected from high and low plant density conditions. However, most outstanding crosses were from diallel crosses within the RFL and MSL lines. One of the crosses was from lines of common parents, thereby substantiating the important role of additive gene action for the yielding ability of a hybrid. However, lines of common parents from RFL set 2 and RFL set 4 performed consistently well. Therefore, logically, RFL selection should be a good option for early generation screening because it provides the chance for improvement of the line per se performances through recurrent cycles. However, the performance of final selected lines should be evaluated in crosses.
Keywords: composite line, recurrent selection methods, corn, mass-sib selection, hybrid

INTRODUCTION

Pedigree selection to differentiate the few best lines from thousands of individuals in a population is a time-consuming process and requires a high investment of resources. However, to increase the chance of a successful inbred result, breeders have accepted a step-by-step procedure for inbred improvement, by practicing pedigree selection of elite line crosses in the segregating population (Hallauer, 1990). As a rapid approach to elite germplasm, Ipsilandis *et al.* (2005) suggested F_2 segregation of a commercial hybrid as the starting breeding material to avoid population improvement and exploitation of favorable additive gene action. Besides, the widespread commercial use of single cross hybrids has increased the importance of the performance of an inbred line per se. Usually, intense visual selection was practiced in the S_2, S_3, and S_4 generations before evaluating the combining ability of new lines (Bauman, 1981). To enhance full expression of individual plants in the segregating population and hence improve the

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efficiency of visual selection, Fasoula and Fasoula, (2000) suggested selection under a nil-competition environment. In contrast, Troyer and Rosembrook (1983) selected for stress tolerance and widely adapted inbreds under conditions of high plant density.

However, Genter (1967) expressed the opinion that the most serious obstacle to obtaining highly productive inbred lines was the rapid approach to homozygosity under continuous selfing in consecutive generations. In addition, Genter (1976) found that alternate S_1-full sib selection in the F_2 generation of a single cross rendered not only a higher population yield, but also a full sib progeny that yielded equally to the original single cross hybrid. Furthermore, Cornelius and Dudley (1974) found that at the same rate of inbreeding, full sib progenies, Sib_3 and Sib_6 rendered higher yields than S_1 and S_2, respectively. On the other hand, for a small breeding program with limited resources, Kinman (1952) suggested a selective mass sibbing to stabilize the yielding ability of the S_1 line in later segregating generations and to promote the production of early generation hybrids, where uniformity of the hybrid is not a priority. Furthermore, Phuong *et al*. (2007) proposed alternate S_1-full sib selection in a few individual S_1 lines selected under a low competition environment, in order to accumulate additive genes in the later generation of the composite-sibbed line. A small segregating S_1 population is used to provide limited space for additional numbers of the segregating population. The proposed method operated under the assumptions: 1) the breeding program is small with limited resources; 2) there is no correlation between single plant yield in the early generations and the yield of the corresponding line in later generations (Cornelius and Dudley,1974), and therefore seeking the highest single plant yield in a large segregating population in an early generation is impractical; 3) performance of a line per se separates inbred lines into groups of high- and low-combining ability, but individuals of each group are not related to either the specific or general combining ability (Lamkey and Hallauer, 1986); and 4) single plant yield could be stabilized and an early generation hybrid could be constructed by a composite sibbed line in an early generation, provided that uniformity of the hybrid is not a priority (Kinman,1952). The present study follows from the research of Phuong *et al.* (2007) and Mapakhe (2008), to elaborate the expression of hybrids derived from composite sibbed lines.

MATERIALS AND METHODS

Three selection methods were used in the study composed of: 1) selfed family line selection (SFL), where the three best plants within each family row are selfed and seeds are bulked for further selfing and selection; 2) mass sibbed line selection (MSL), where each S_1 progeny is grown in two adjacent rows. Bulk pollen of the best three plants in one row is pollinated to the best three plants in the adjacent row and the crossed seeds are used for further selection; and 3) Alternate S_1-full sib selection, referred to as a recurrent S_1-full sib selection (RFL), where each S_1 progeny is grown in three adjacent rows and the best plant in each row is crossed in all possible combinations. The three derived F_1 ears are then grown in three adjacent rows and the best F_1 plant in each row is selfed for selection in the next recurrent cycle.

From previous studies, six commercial corn hybrids were used as starting material. Visually, 54 S_1 progenies were selfed and 18 sets of three ears were formed and SFL and RFL were applied to each group, respectively. Based on the testcrosses and line per se performance, 6 SFL and 6 RFL were selected (Phuong *et al.,* 2007). Consequently, each set of 6 RFL was separated into 3 sublines and each subline was subjected to MSL and RFL selection. Out of 18 MSL and 18 RFL sublines, 6 of each were selected by line performance per se and their combining ability (Mapakhe, 2008). Afterward, the derived 6 SFL (S_6), 6 RFL cycle$_3$ (F_1) and 6 MSL cycle$_3$ were used as starting breeding materials of the present study. However, each line was separated into a pair of lines, totaling 6 pairs of SFL (S_6), 6 pairs of 6 RFL cycle$_3$ (F_1) and 6 pairs of MSL cycle$_3$. The processes of selection which were applied to each line were continued, but selection was carried out under high (plant spacing 0.75×0.25 m) and low (honeycomb planting, plant-to-plant spacing at 0.866 m) plant densities. After two generations of selection, 6 pairs of SFL (S_8), 6 pairs of RFL cycle$_4$ (S_1) and 6 pairs of MSL cycle$_5$ were obtained. Visually, the best 2 lines from each selection method in each plant density were independently selected. The derived 6 lines from the high plant density and 6 lines from the low plant density selection were crossed in all possible combinations within each group. As a result, two sets of 15 diallel crosses were obtained. Simultaneously, 18 lines from the high plant density and 18 lines from the low plant density were testcrossed to an inbred to form two sets of 18 testcrosses from high and low plant density selection. All selection processes from previous studies, as well as in this study, were conducted under low plant density in honeycomb planting, with plant spacing at 0.866 m. However, all yield trials were conducted under high plant density (0.75×0.25 m).

For the current study, all yield trials were grown in adjacent areas of the same block in a randomized complete block design, with 3-row plots, each 5 m long and with four replications.

A computer program (SPSS version 13) and quantitative genetic analysis in plant breeding diallel cross design software were applied to compute ANOVA and the combining ability of each line, respectively. All experiments were conducted at the National Corn and Sorghum Research Center, Suwan Farm in Nakhon Ratchasima province (14°13′N, 101°30′E, at 356 m above sea level).

RESULTS AND DISCUSSION

At the end of selection processes, the SFL, RFL and MSL lines were passed through eight generations of selection, roughly equivalent to S_8, S_5 (4 selfing + 4 full sibbing) and S_3 (2 selfing + 1 full sibbing + 5 mass sibbing), respectively. However, with selection for the same plant type in each line, the MSL was expected to have an inbreeding rate somewhat higher than the S_3 line (Kinman, 1952). Thus, the inbreeding rate of each group of lines should be about 99.6%, 96.8% and slightly higher than 87.5%, respectively. In fact, selection enhanced greater uniformity in the SFL and RFL lines, as well as the MSL lines.

Diallel crosses of visually selected inbreds from different methods under high plant density are presented in Table 1. The RFL set 4-402-3 and the RFL set 2-401-5 predominated in the hybrid combinations of the top-3 crosses, while the MSL set 5-402-4 and SFL 403-6 interacted with the two former lines to form good hybrids. The general combining ability (GCA) of RFL set 4-402-3, RFL set 2-401-5, SFL 403-6 and MSL set 5-402-4 were positive; 1.44**, 1.09**, 0.49 and 0.34, respectively. However, the best combination was the MSL set 5-402-4/ RFL set 4-402-3, which yielded 8.99 ton/ha but this was not significantly different from the best check (KR-71), which yielded 7.37 ton/ha. In addition, the top two GCA lines were derived from crosses of a common parent and therefore, additive gene action (GCA) played a major role in determining the high yielding ability of the top hybrids.

Different sublines were selected by RFL and MSL under high plant density conditions (Table 2). However, some of the same sublines from the original set 2-401-5, set 3-401-9 and set 7-404-4 were selected by MSL and RFL, but they reacted differently with a common tester. Therefore, different methods for composite sibbed lines rendered different performances of sublines, though they were derived from the same common

Table 1 Grain yield at 15% moisture content and other characteristics of 15 diallel crosses of six inbreds selected under high plant density, planted in June 2008 at Suwan Farm, Nakhon Rachasima, Thailand.

Diallel crosses	Yield (ton/ha)	% of KR-71	Days to anthesis	Days to silking	Moisture (%)	Shelling (%)
MSL Set-5 402-4 x RFL Set-4 402-3	8.99[a1/]	122.00	53.75	56.25	31.93	81.25
RFL Set-2 401-5 x RFL Set-4 402-3	8.75[ab]	119.00	58.00	59.25	34.85	82.00
RFL Set-2 401-5 x SFL 403-6	7.47[abc]	101.00	56.25	58.00	31.95	76.75
MSLSet-3 401-9 x SFL 403-6	7.46[abc]	101.00	55.75	57.25	29.73	78.75
KR-71 (check-1)	7.37[abc]	100.00	58.25	59.25	35.02	76.25
SFL 403-6 x SFL 402-7	7.25[abc]	98.00	52.50	54.00	31.00	77.75
MSLSet-3 401-9 x RFL Set-4 402-3	6.96 [bcd]	94.00	54.75	56.25	31.15	80.75
MSL Set-5 402-4 x RFL Set-2 401-5	6.80[cd]	92.00	56.00	57.50	31.33	77.00
MSLSet-3 401-9 x MSL Set-5 402-4	6.35 [cd]	86.00	54.50	55.00	32.30	77.50
RFL Set-2 401-5 x SFL 402-7	6.03[cde]	82.00	55.75	57.50	32.00	79.25
KR-72 (check-2)	5.77 [cde]	78.00	54.00	56.25	34.18	76.00
RFL Set-4 402-3 x SFL 403-6	5.75 [cde]	78.00	55.50	56.50	30.70	77.75
MSLSet-3 401-9 x RFL Set-2 401-5	5.75[cde]	78.00	57.25	58.50	30.57	80.25
MSL Set-5 402-4 x SFL 403-6	5.70[cde]	77.00	55.00	56.75	32.40	74.25
MSL Set-5 402-4 x SFL 402-7	5.47 [cde]	74.00	54.25	55.75	30.75	79.00
RFL Set-4 402-3 x SFL 402-7	5.06[de]	69.00	54.50	56.75	33.25	77.00
MSLSet-3 401-9 x SFL 402-7	4.08[e]	55.00	58.50	60.00	33.18	77.00
Maximum	8.99	122.00	58.50	60.00	35.02	82.00
Minimum	4.08	55.00	52.50	55.00	29.73	74.25
Mean	6.53	89.00	55.55	57.10	32.16	78.14
F Test	**		**	**	**	*
CV (%)	18.2		1.97	1.84	6.54	3.71
LSD (0.05)	1.69		1.55	1.25	2.99	0.041

Note: * = significant; ** = highly significant.

[1/] Means in the column that are followed by the same letter(s) were not significant at $P<0.05$ by LSD.

line. Moreover, each of the top three testcrosses in Table 2 was from lines of each method of selection (MSL, RFL and SFL). As a result, there was no clear advantage in any of the selection methods for combining ability of the derived lines in testcrosses. Kinman (1952) also found that selfed lines and mass sibbed lines rendered similar results in testcrosses, but mass sibbed lines had much higher yields than the selfed lines. Although yield data of inbreds used in the present study is not available, inbred yields of the previous cycle (Mapakhe, 2008) were in the order of MSL > RFL > SFL, which coincided with the inbreeding rate of each method of selection.

A set of 15 diallel crosses of inbreds visually selected under low plant density is presented in Table 3. Selection under high (Table 1) and low (Table 3) plant densities rendered different lines or sublines and thus, lines reacted differently under high and low plant densities. The MSL set 7-404-6, which possessed a high GCA (4.16**) predominated the top three diallel crosses in Table 3. The MSL set 4-402-2 possessed a positive GCA (0.3), but its sister lines from different methods of selection (RFL set 4-402-1) possessed a negative GCA (-0.78) and the SFL 401-6 from selfed family selection also had a negative GCA (-0.14). However, all of these lines

Table 2 Grain yield at 15% moisture content and other characteristics of 15 testcrosses of inbreds selected under high plant density, planted in June, 2008 at Suwan Farm, Nakhon Rachasima, Thailand.

Testcrosses	Yield (ton/ha)	% of KR-71	Days to anthesis	Days to silking	Moisture (%)	Shelling (%)
MSL Set-3 401-9 x KI 62	9.36[a1/]	115.56	55.00	57.00	31.95	79.00
RFL Set-2 401-5 x KI 62	9.30[a]	114.81	57.00	58.00	31.88	80.00
SFL 402-7 x KI 62	8.94[ab]	110.37	53.00	53.75	33.25	78.75
KR-71 (check-1)	8.10[abc]	100.00	58.25	59.00	33.33	77.50
MSL Set-4 402-1 x KI 62	7.27[bcd]	89.75	55.25	56.75	33.08	78.50
RFL Set -4 402-3 x KI 62	7.22[bcd]	89.14	54.50	55.75	33.20	79.25
SFL 401-9 x KI 62	7.17 [bcd]	88.52	54.25	55.50	32.38	77.75
SFL 403-3 x KI 62	6.91[cd]	85.31	56.00	57.00	34.40	78.00
SFL 401-6 x KI 62	6.63[cd]	81.85	56.25	57.50	34.88	78.25
RFL Set-3 401-9 x KI 62	6.47[cd]	79.88	54.75	56.25	33.65	76.75
RFL Set-7 404-4 x KI 62	6.45[cd]	79.63	56.00	57.00	32.13	78.75
MSL Set-11 406-2 x KI 62	6.31[cd]	77.90	57.25	59.00	33.45	74.00
MSL Set-5 402-4 x KI 62	6.09 [d]	75.19	54.25	55.25	32.48	81.00
KR-72 (check-2)	6.04[d]	74.57	57.75	59.25	32.55	77.50
MSL Set-7 404-4 x KI 62	5.91 [d]	72.96	56.75	57.50	32.03	77.50
MSL Set -2 401-5 x KI 62	5.90 [d]	72.84	56.00	57.00	31.23	79.00
RFL Set-5 402-6 x KI 62	5.71[d]	70.49	55.25	56.75	33.25	76.50
Maximum	9.36	115.56	58.25	59.25	34.88	81.00
Minimum	5.71	70.49	53.00	53.75	31.23	74.00
Mean	7.10	87.62	55.72	56.93	32.91	78.05
F Test	**		**	**	ns	**
CV (%)	17.10		1.8	2.20	7.80	2.45
LSD (0.05)	1.71		2.33	1.84		1.98

Note: ns = non significant; * = significant; ** = highly significant.

[1/] Means in the column that are followed by the same letter(s) were not significant at P<0.05 by LSD.

rendered good combinations with MSL set 7- 404-6. The top two combinations (MSL set 7 -404-6/ SFL 401-6 and MSL set 7-404-6/ RFL set 4 402-1) had significantly higher yields than the best check (KR-71). This finding substantiated that the GCA and the specific combining ability (SCA) in the right combination is required for an outstanding hybrid. Testcrosses of lines selected under low plant density rendered similar results to the testcrosses of lines selected under high plant density (Tables 2 and 4). However, none of the top three testcrosses was significantly different from KR-71. In addition, the mean yield of both sets of diallel crosses and both sets of testcrosses was not much different and thus there was no clear distinctive performance of lines selected from both low and high plant densities in hybrid combinations. However, sublines from RFL set 2 and sublines from RFL set 4 were always present in the top three combinations of all yield trials. The results substantiated previously reported good performances by RFL set-4 and RFL set-2 in the first phase (Phuong *et al.*, 2007) and second phase (Mapakhe, 2008) of selection.

The consistency of lines selected from the RFL method over other methods hinted logically that the RFL method should be a good choice for early generation screening of inbred

Table 3 Grain yield at 15% moisture content and other characteristics of 15 diallel crosses of six inbreds selected under low plant density planted in June, 2008 at Suwan Farm, Nakhon Rachasima, Thailand.

Diallel crosses	Yield (ton/ha)	% of KR-71	Days to anthesis	Days to silking	Moisture (%)	Shelling (%)
MSL Set-7 404-6 x SFL 401-6	9.61 a[1/]	121.00	55.50	56.50	33.58	78.75
MSL Set-7 404-6 x RFL Set-4 402-1	9.44 ab	119.00	54.75	56.00	31.83	80.00
MSLSet-4 402-2 x MSL Set-7 404-6	9.30 ab	117.00	55.00	56.25	32.07	77.25
KR-71 (check-1)	7.93 bc	100.00	58.75	59.25	34.43	76.00
MSLSet-4 402-2 x RFL Set-2 401-4	7.65 cd	96.00	54.75	56.25	28.25	78.75
MSL Set-7 404-6 x MSL Set-2 401-4	7.59 cd	96.00	57.50	59.50	32.53	82.00
RFL Set-4 402-1 x SFL 401-6	7.51 de	95.00	57.25	58.50	32.90	79.75
MSL Set-7 404-6 x SFL 403-3	7.30 cde	92.00	54.50	55.00	32.03	76.00
MSLSet-4 402-2 x SFL 401-6	6.75 cde	85.00	57.50	58.75	34.53	77.75
KR-72 (check-2)	6.57 cde	83.00	57.00	57.25	33.30	79.25
SFL 401-6 x SFL 403-3	6.54 cde	82.00	56.75	57.75	32.75	75.00
RFL Set-2 401-4 x SFL 403-3	6.50 cde	82.00	59.00	59.25	32.23	77.75
MSLSet-4 402-2 x RFL Set-4 402-1	5.93 def	75.00	55.50	56.50	29.68	78.00
MSLSet-4 402-2 x SFL 403-3	5.90 def	74.00	57.50	59.00	32.33	79.00
RFL Set-2 401-4 x RFL Set-4 402-1	5.80 efg	73.00	57.50	58.50	32.20	79.25
RFL Set-4 402-1 x SFL 403-3	4.73 fg	60.00	55.75	56.75	31.03	75.50
RFL Set-2 401-4 x SFL 401-6	4.25 fg	54.00	58.25	59.25	33.38	76.75
Maximum	9.61	121.00	59.00	59.50	34.53	82.00
Minimum	4.25	54.00	54.50	55.00	28.25	75.00
Mean	7.01	88.00	56.64	59.67	32.20	78.09
F Test	**		**	**	**	**
CV (%)	15		1.88	1.8	6.77	2.54
LSD (0.05)	1.50		1.51	1.49	3.12	2.83

Note: ** = highly significant.

[1/] Means in the column that are followed by the same letter(s) were not significant at P<0.05 by LSD.

lines. It reduced the number of lines for combining ability testing in the early generations as compared to the continuous selfing method, while increasing the chance of improving line per se performances through recurrent cycles. With the same number of generations, the inbreeding rates of a recurrent S_1-full sib selection (RFL) and the consecutive selfing method were slightly different and therefore the uniformity of lines selected from both methods was high. However, the RFL method provides for the chance of the improvement of line per se performances in each generation, instead of fast fixing of homozygous genes through continuous selfing. If desired, lines of a RFL could be separated in later cycles to improve the uniformity of lines. In addition, the performance of a line should be stabilized if large numbers of plants were mass sibbed (Kinman, 1952) and therefore performance of a line per se should be maintained by the MSL method to stabilize line performances per se. While line per se performance is desired for single cross hybrids, the ultimate value of a line in hybrids must be determined in crosses to testers and crosses of elite lines (Hallauer, 1990).

Table 4 Grain yield at 15% moisture content and other characteristics of 11 testcrosses of inbreds selected under low plant density, planted in June, 2008 at Suwan Farm, Nakhon Rachasima, Thailand.

Testcrosses	Yield (ton/ha)	% of KR-71	Days to anthesis	Days to silking	Moisture (%)	Shelling (%)
RFL Set-2 401-4 x KI-62	9.34$^{a1/}$	113.49	55.75	56.50	30.27	80.25
RFL Set-4 402-3 x KI-62)	8.70 ^{ab}	105.83	57.25	58.00	32.93	79.00
MSL Set-3 401-9 x KI-62	8.24^{abc}	100.12	56.00	56.25	31.35	79.00
KR-71 (check-1)	8.23 ^{abc}	100.00	59.00	59.25	33.10	78.00
MSL Set-5 402-6 x KI-62	8.10 ^{abcd}	98.42	56.00	57.00	32.83	79.75
SFL 402-6 x KI-62	7.91 ^{abcd}	96.11	56.25	57.00	31.10	79.25
MSL Set-4 402-2 x KI-62	7.55 ^{abcd}	91.74	57.00	57.75	33.50	78.75
MSL Set-7 404-6 x KI-62	7.42 ^{abcd}	90.16	56.75	57.50	28.28	79.00
RFL Set-4 402-4 x KI-62	7.29^{bcd}	88.58	55.00	56.50	31.88	80.00
MSL Set-2 401-5 x KI-62	7.11^{bcd}	86.39	56.75	57.00	31.98	80.75
MSL Set-11 406-3 x KI-62	6.41^{cd}	77.89	57.50	58.75	32.50	75.75
KR-72 (check-2)	6.37 ^{cd}	77.40	55.75	56.75	31.18	79.00
SFL 403-6 x KI-62	6.20^{d}	75.33	57.00	57.75	29.93	76.50
Maximum	9.34	113.49	59.00	59.25	33.50	80.75
Minimum	6.20	75.33	55.00	56.25	28.28	75.75
Mean	7.63	92.69	56.67	57.38	31.51	78.77
F Test	**		ns	ns	ns	**
CV (%)	15.40		2.70	2.30	7.00	18.00
LSD (0.05)	1.68					2.00

Note: ns = non significant; ** = highly significant.

1/ Means in the column that are followed by the same letter(s) were not significant at P<0.05 by LSD.

MSL set 3 = Pacific 984, RFL set 2 = Pacific 984, RFL set 4 = Monsanto 949, SFL 401 = Pacific 984, MSL set 7 = Pioneer A33, MSL set-5 = Monsanto 949, SFL 403 = Monsanto

CONCLUSION

For diallel crosses, most outstanding crosses were derived from combinations of mass-sibbed lines (MSL) and recurrent S_1-full sibbed lines (RFL). While there was no clear advantage in selecting MSL and RFL lines under different plant densities in their hybrid combinations, RFL set 4 and RFL set 2 showed consistently high performance in different sets of germplasm. Logically, the RFL method should be a good choice for early generation screening of inbred lines. It provides the opportunity for improvement of line per se performance through recurrent cycles. Lines with high GCA and SCA are required for outstanding crosses. Since good hybrid combinations changed according to the different sets of germplasm, the ultimate value of line per se performance must be evaluated in crosses.

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