

Composite Line Method for the Development of Early Generation Hybrids of Maize (*Zea mays* L.)

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ABSTRACT

Six commercial single crosses were used for the improvement of composite and inbred lines. Modified S_1 -full sib selection was applied to improve the three sister line composite. Lines were visually selected under low-competition environment in honeycomb arrangement with equilateral triangular side of 0.866 m. Testcross as well as diallel cross were applied to identify high combining lines. All yield trials were conducted in randomized completed block design with 4 replications, 1 row plot of 5 m long and 0.75×0.25 m plant spacing. Standard cultural practices were regulated and irrigation was applied as needed.

Statistically, there was no clear advantage of yield between composite and inbred lines in early generation testcrosses. Besides, the diallel sets of both groups of lines gave similar results. However, the top hybrids of overall trials came from composite crosses even though it was not significant. In addition, composite lines were superior to S_3 lines in yield, earliness and plant height. Modified S_1 -full sib selection is a flexible breeding method but its merit for the construction of early generation hybrids must be thoroughly investigated even though the positive results were observed.

Key words: maize breeding, testcross, honeycomb, composite line

INTRODUCTION

Development of single cross hybrid of maize is the ultimate goal of most of maize breeding programs. However, finding stable high yield inbred lines to ensure the high level of economic return for commercial hybrid seed production is the main obstacle of small and new emerged single cross development programs. Combined line selection and testing for combining ability is time and space consuming processes. Instead of five or six generations of selfing usually practiced in the development of inbred lines, composite-sibbing lines from individual of S_1

progenies have been proposed (Kinman, 1952). The method fixed the composite-sibbed lines since the first selfing and therefore improvement in the combining ability or other characteristics of composite-sibbing lines can not be made after several generations of mass sibbing unless effective selection is practiced. In other way, line selection from cross between closely related parents has been proved to be an effective method for inbred line development (Rasmusson and Phillips, 1977; Troyer, 1999). Selection for high and low yield lines effectively separated lines into high and low combining ability groups but yield of lines within group cannot be used as criterion

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for combining ability of lines (Lamkey and Hallauer, 1986). In addition, for effective differentiation of lines, Fasoula and Fasoula (1997) proposed line selection under nil-competition environment in honeycomb designs. In order to improve yield and combining ability of population, Landi and Frascaroli (1993) applied full-sib selection in F_2 population of single cross. The method proved to be very effective for several cycles of selection. However, the previous study of Genter (1976) which applied the same method suggested that using S_1 instead of S_0 to form full-sibs was more effective to identify high yielding full-sibs as well as in improvement of population per se. This finding agreed well with suggestion of Lonnquist (1950) that testing for combining ability after one generation of selfing is desirable when the composite sib-breeding method is used.

The above finding suggested that alternate selfing and full sibbing among few closely related lines under low-competition environment should lead to uniform, high yield and high combining composite lines as high level of homozygosity is approached and provide a chance for continuous improvement of composite lines in the successive cycles.

The present study therefore aim to formulate the effective breeding method for the development of composite lines and evaluate its merit as compared to the conventional line selection with early generation testing for combining ability. The modified S_1 -full sib selection within related lines is proposed.

MATERIALS AND METHODS

Six commercial single cross hybrids comprised Monsanto 949, Monsanto 919, Pioneer A33, Pioneer 3012, Pacific 984 and Syngenta NK 48 were planted in normal plant spacing (0.75×0.25 m) and selfed to obtain S_1 ears. Nine S_1 ears within each family were randomly grouped in to 3 ear sets, 3 sets per family and therefore resulted

in 18 sets of 3 S_1 and 54 individual S_1 lines. They were separately ear-rowed in honeycomb arrangement (HC) with equilateral triangular side of 0.866m. Three best S_1 plants within each set were intercrossed (full sibbing) to form 18 intra-set diallel crosses which will be referred to as full sib sets while 3 best S_1 plants from each family were also selfed to obtain 18 S_2 lines.

Consequently, they were ear-rowed in HC, the 18 S_2 plants were selfed as well as testcrossed to the inbred tester, KRi 208 to obtain 18 S_3 lines and 18 testcrosses, $S_2 \times$ KRi 208 hybrids. The best S_2 lines by visual selection, one from each family, were also intercrossed to form 15 diallel crosses of 6 S_2 . In the meantime, the best 3 F_1 plants from each full sib set were crossed in all possible combinations to form 18 composite lines and they will be referred to as composite line cycle-1 (C#1). The method is essentially similar to S_1 and full-sib selection of which it will be referred to as modified S_1 -full sib selection for composite line development. Afterward, C#1 were testcrossed to KRi 208. As a result, 18 C#1 testcrosses were obtained. In addition, the best C#1 by visual selection, one from each family, were intercrossed to form 15 diallel crosses of 6 C#1.

Yield trials of 18 S_3 lines, 18 C#1, 18 testcrosses of $S_2 \times$ KRi 208, 18 testcrosses of C#1 \times KRi 208, 15 diallel crosses of 6 C#1 and 15 diallel crosses of 6 S_2 lines were conducted in separate trials in adjacent areas in randomized completed block design with 4 replications, 1 row plot of 5m long and 0.75×0.25 m plant spacing. Five original hybrids were included as common checks in all hybrid yield trials. Pacific 984 was excluded and replaced by Suwan 4452 because the former was dropped out from the market and there was no seed available.

All experiments were conducted from September 2004 to March 2006 at National Corn and Sorghum Research Center, Suwan Farm, in Nakhon Ratchasima province ($14^{\circ}30'N$, $101^{\circ}30'E$, and 356m asl.), Thailand under standard cultural

practices. Basal fertilizers were applied at planting time at the rate of 75 kg ha⁻¹ of N and 100 kg ha⁻¹ of P₂O₅. Top-dressing was done at the 6 to 8 leaf stages with the rate of 75 kg N ha⁻¹. Pre-emergence herbicides, Atrazine and Alachlor were used by mixing at the rate 1.5 and 1 kg a.i. per ha, respectively. Thinning was done at 14 days after sowing. Irrigation was applied when necessary.

RESULTS AND DISCUSSION

Mean grain yields and other agronomic traits of top-10 S₃ lines are presented in Table 1. All selected lines were statistically not different except line 406-3 and only line 401-6 showed significant difference over the inbred check, KRi 208. However, the KRi 208 had higher level of homozygosity and therefore, if further inbreeding was applied, all lines were expected to be similar in yield level. There was no clear evidence for the advantage or disadvantage of other agronomic traits among the top ten lines but line 403-5

demonstrated a superior shelling percentage over other lines including the checks.

In comparison S₃ with C#1 lines, the C#1 lines were consistently superior in the characteristics used as measures of vigor; grain yield, earliness of anthesis and silking, plant and ear height. They were earlier, taller and had higher yield regardless of germplasm sources. Moreover, better distribution of germplasm sources of top-10 C#1 was evident. All six germplasm sources were present in the top-10 C#1 while in the top-10 S₃ lines, visual selection leaned toward Monsanto 949 and Pacific 984. The results indicated that C#1 was more stable by outcrossing. On the other hand, inbred lines from each germplasm source should have different level of inbreeding depression and thus selection for performance per se was biased toward the less inbreeding depression germplasm. In this case, Pioneer 3012 was lost from the top-10 S₃ lines.

The present results agreed well with report presented by Kinman (1952) of which

Table 1 Grain yields at 15 percent moisture and other agronomic traits of top 10 S₃ lines and KRi 208 at Suwan Farm, Thailand in November 2005 (dry season).

S ₃ lines	Source of germplasms	Grain Yield (ton/ha)	Days to Anthesis (days)	Days to Silking (days)	Moisture Content (%)	Plant Height (cm)	Ear Height (cm)	Shelling (%)
401-6	Pac.984	4.21 a	68.7 a-d	69.0 bcd	21.9 a-d	131.5	54.2 bc	76.6 a-d
402-6	Mon.949	3.77 ab	68.3 a-e	67.3 edf	25.6 a	140.2	60.3 abc	73.6 bcd
404-4	Pio.A33	3.71 ab	67.7 b-f	67.3 edf	23.7 abc	140.3	63.5 abc	73.9 bcd
402-8	Mon.949	3.63 ab	66.7 ef	67.0 ef	24.9 ab	134.3	60.7 abc	75.6 bcd
401-9	Pac.984	3.40 ab	70.0 a	68.8 b-e	23.4 a-d	131.3	54.3 bc	79.1 ab
402-7	Mon.949	3.38 ab	66.3 f	66.3 f	23.9 abc	138	52.3 c	75.7 bcd
405-4	Syn. 48	3.36 ab	67.0 def	67.7 c-f	22.8 a-d	134.7	60.5 abc	71.8 cd
403-5	Mon.919	3.21 abc	68.0 b-f	68.0 b-f	20.2 cd	126	52.3 c	82.2 a
401-7	Pac.984	3.08 a-d	70.0 a	69.0 bcd	22.0 a-d	131.5	58.7 abc	78.0 ab
406-3	Pio.3012	2.89bcd	70.0 a	68.8 b-e	24.5 ab	151.5	68.2 ab	74.6bcd
KRi 208	Pio.3012/3013	3.01bcd	69.0 abc	69.7 ab	25.5 a	120.3	50.2 c	73.5 bcd
	Mean	3.48	68.2	68.0	23.4	132.8	56.7	76.0
	F-value ^{1/}	**	**	**	**	ns	**	**
	CV(%)	19.568	1.338	1.353	8.489	10.561	13.461	3.973

^{1/} ns: non significant, * : significant, ** : highly significant

selective mass sibbing within individual S_1 progenies was used. In Kinman's words, the population is closed at the time of first sibbing, it should not be expected that improvement in the combining ability or other characteristics of composite-sibbed lines will be made even after several generations of mass sibbing unless effective selection is practiced. Unlike Kinman's method, the modified S_1 -full sib selection employed in the present study provided a more flexible approach. Selection for S_1 performance per se alternate with diallel cross of individual of 3 selected S_1 lines (full sibbing) should improve general combining ability as well as specific combining ability of S_1 lines from successive cycles. In the meantime, the newly emerged individual S_1 as well as full sib of each cycle can be fixed by mass sibbing method and used in early generation hybrid combinations while the successive cycles of composite sets move slowly toward higher level of homozygosity and hence more uniform lines and hybrids in later stages.

Lamkey and Hallauer (1986) found that

inbred line performance per se can be used as a criterion to differentiate combining ability between high and low yield inbreds. However, yield per se within high or low yielding groups cannot be used to predict line performance in hybrid combinations. Yielding ability of line per se in Table 1 and their testcross performance in Table 3 clearly supported the above finding. Since all 18 inbred lines came from the top-3 high yield lines of each original hybrid therefore they should be considered high yield lines. However, their yielding ability did not represent the combining ability of lines in the testcross combinations with the inbred tester (KRi 208), line 403-4 which was excluded from the top-10 lines gave the highest yield in the testcrosses while the top yield line, 401-6 ranked 9th in testcrosses. Besides, only two Pioneer lines, 406-1 and 404-4 were present in the top-10 testcrosses. This is not unexpected because the tester line, KRi 208 derived from Pioneer 3012/ Pioneer 3013. Therefore, genetic background of tester played an important role in the combinations with tested lines. However, 406-1/KRi 208 is

Table 2 Grain yields at 15 percent moisture and other agronomic traits of composite lines of cycle 1st at Suwan Farm, Thailand in November 2005 (dry season).

Composite lines	Source of germplasms	Grain Yield (ton/ha)	Days to Anthesis (days)	Days to Silking (days)	Moisture Content (%)	Plant Height (cm)	Ear Height (cm)	Shelling (%)
Set 4	Mon.949	6.13 a	67.3 abc	67.3 bc	25.5 a	168.7	82	77.2
Set 5	Mon.949	5.53 ab	65.0 d	67.0 bc	25.6 a	165.6	71.2	79.2
Set 18	Mon.919	5.26 abc	63.0 e	66.0 c	21.4 cd	157.4	63.9	80.8
Set 10	Syn. 48	4.91 bc	66.0 cd	66.7 bc	21.9 bcd	173.3	80.3	79.6
Set 11	Syn. 48	4.87 bcd	66.0 cd	67.0 bc	22.9 bcd	161.2	67.7	72.9
Set 2	Pac.984	4.81 bcd	68.3 ab	67.7 bc	23.8 abc	171.8	75.2	79.4
Set 8	Pio.A33	4.66 bcd	66.7 a-d	67.0 bc	22.8 bcd	165.8	80.8	80.2
Set 14	Pio.3012	4.64 bcd	68.0 abc	67.7 bc	22.0 bcd	158.1	69.2	80.2
Set 3	Pac.984	4.63 bcd	68.7 a	68.3 ab	23.8 abc	159.3	65.5	79.7
Set 7	Pio.A33	4.58 bcd	66.3bcd	67.0 bc	22.6 bcd	150.3	67.7	79.5
	Mean	5.00	66.5	67.2	23.2	163.2	72.4	78.9
	F-value ^{1/}	*	**	*	**	ns	ns	ns
	CV(%)	14.076	1.73	1.575	5.815	7.111	15.454	3.299

^{1/} ns: non significant, * : significant, ** : highly significant

essentially a backcross to sister line and ranked 6th in the top-10 testcrosses indicated a strong additive effect in this hybrid combination. Since different testers gave different performance with the same group of lines (Castellanos *et al.*, 1998), all high yield lines should be tested for their hybrid combinations directly to their counterpart parental lines to identify the best hybrid combination.

Statistically, all top-10 testcrosses yielded as high as the top-4 checks but somewhat better than Monsanto 949 and Monsanto 919. However, 403-4/KRi 208 gave an outstanding feature of yield and earliness even though it was taller and lower in shelling percentage than the average.

Top S₂ lines, one from each of six original hybrids were intercrossed and the top-10 interfamily hybrids are presented in Table 4. As expected, the average of top-10 S₂ interfamily diallel hybrids was lower than that of top-10 S₂ testcrosses because both parental lines of S₂-interfamily hybrids were more heterogeneous than the tester line, KRi 208 in S₂ testcrosses. Therefore, the specific combining ability of lines were more pronounced. Seven out of 10 S₂-interfamily hybrids were involved with Pioneer 404-6 and Pioneer 406-1 and 6 out of 10 were crosses between Pioneer and Monsanto lines. Evidently, both germplasm sources complimented each other of which they showed a good heterotic pattern.

Table 3 Grain yields at 15 percent moisture and other agronomic traits of top 10 testcrosses between selected S₂ × KRi 208 and original hybrids conducted at Suwan Farm, Thailand in November 2005 (dry season).

Lines × KRi 208 ^{2/}	Source of germplasms	Grain Yield (ton/ha)	Days to Anthesis (days)	Days to Silking (days)	Moisture Content (%)	Plant Height (cm)	Ear Height (cm)	Shelling (%)
403-4	Mon.919	8.96 a	61.3 h	61.7 j	22.6 def	165.8 b-f	81.7 a-f	75.9 h-k
405-5	Syn. 48	8.82 ab	62.3 e-h	64.0 d-i	23.0 c-f	153.3 fgh	70.3 fg	77.1 f-i
402-6	Mon.949	8.40 a-d	62.0 fgh	62.7 hij	24.9 abc	161.0 d-h	80.3 a-f	75.3 k
405-4	Syn. 48	8.14 a-e	61.7 gh	62.3 hij	23.2 c-f	158.0 d-h	79.0 b-g	77.5 efg
405-6	Syn. 48	8.08 a-f	63.3 b-g	64.3 b-g	24.3 bcd	157.6 d-h	82.7 a-f	75.6 ijk
406-1	Pio.3012	8.07 a-f	63.0 c-h	63.7 e-i	24.1 bcd	164.2 b-f	81.7 a-f	78.3 def
402-7	Mon.949	8.00 a-f	61.3 h	62.0 ij	24.0 bcd	150.0 gh	73.7 d-g	77.0 f-i
404-4	Pio.A33	7.89 a-f	65.0 ab	65.3 c-f	23.6 b-f	159.8 d-h	76.8 b-g	75.4 jk
401-6	Pac.984	7.70 a-g	62.7 e-h	63.3 f-j	23.4 c-f	156.3 e-h	72.7 d-g	79.5 cd
403-5	Mon.919	7.66 a-g	62.0 fgh	62.7 hij	21.9 ef	162.1 c-h	89.8 a-g	81.1 bc
Check	Pio.A33	8.47 abc	64.7 bc	66.0 bcd	21.9 ef	182.0 a	91.9 a	79.8 bc
Check	SW 4452	8.24 a-e	66.7 a	68.7 a	25.0 abc	177.3 ab	84.2 a-e	76.3 g-k
Check	Pio.3012	8.08 a-f	66.7 a	68.0 ab	22.4 def	165.2 b-f	89.1 ab	77.2 fgh
Check	Syn. 48	7.86 a-f	64.0 b-e	66.0 bcd	22.7 def	171.3 a-d	74.4 dfg	77.9 ef
Check	Mon.949	7.57 b-g	62.7 e-h	64.3 d-g	26.7 a	178.3 ab	81.6 a-f	77.9 ef
Check	Mon.919	7.32 c-g	63.3 b-g	65.0 c-g	23.9 b-e	176.1 abc	88.1 abc	82.9 a
	Mean of top 10 topcrosses	8.17	62.5	63.2	23.5	158.8	78.9	77.3
	F-value ^{1/}	**	**	**	**	ns	*	**
	CV(%)	11.006	1.836	1.985	5.198	5.296	9.685	1.179

^{1/} ns: non significant, * : significant, ** : highly significant

^{2/} Pedigree of KRi 208 is Pio.3012/Pio.3013

Although most of S_2 -interfamily hybrids were significantly not different from the checks, 404-6/402-6 (Pioneer A33/Monsanto 949) gave outstanding features for yielding ability, earliness, plant and ear height while retained good shelling percentage. Therefore, beside the conventional testcross program, diallel cross between the top high yield lines is necessary for thorough use of germplasms and identification of new unique hybrid combination.

The numbers of original germplasm sources involved in top-10 S_2 and C#1 testcrosses in Table 3 and 5 were almost the same; 4:5 (Monsanto), 3:3 (Syngenta), 2:1 (Pioneer) and 1:1 (Pacific) indicated that they responded similarly to

the same tester, even though each S_2 line derived from visual selection within each composite set. However, average yield of S_2 testcrosses was higher than that of C#1 testcrosses but top testcross yields of both groups as well as the best check were more or less the same.

The average yield of S_2 diallel crosses in Table 4 and that of C#1 diallel crosses in Table 6 were almost the same but with the higher trend toward the C#1 lines. Evidently, general combining ability of S_2 and C#1 were somewhat the same even though the C#1 were more heterogeneous. Surprisingly, the top-2 hybrids of C#1 gave higher yield over other hybrids and checks tested in the present studies eventhough

Table 4 Grain yields at 15 percent moisture and other agronomic traits of interfamily diallel hybrids of selected S_2 lines and original hybrids at Suwan Farm, Thailand in November 2005 (dry season).

$S_2 \times S_2$	Source of germplasms	Grain Yield	Days to Anthesis (ton/ha)	Days to Silking (days)	Moisture Content (days)	Plant Height (%)	Ear Height (cm)	Shelling (%) (cm)
404-6×402-6	Pio.A33 × Mon.949	8.86 a	62.3 d	63.3 g	25.1 ab	171.9 de	80.5 d-g	76.1 gh
404-6×403-6	Pio.A33 × Mon.919	7.82 abc	62.7 cd	64.3 efg	23.1 b-f	170.3 de	81.7 c-g	77.2 efg
406-1×402-6	Pio.3012 × Syn.48	7.61 bcd	66.3 a	67.3 abc	24.0 b-e	202.3 a	106.9 a	74.8 h
406-1×405-5	Pio.3012 × Syn.48	7.53 b-e	64.0 bcd	65.3 def	24.3 bcd	197.5 ab	96.7 ab	77.4 efg
403-6×401-9	Mon.919 × Pac.984	7.51 b-e	62.3 d	63.7 fg	21.8 efg	169.2 de	77.0 fg	80.6 b
406-1×404-6	Pio.3012 × Pio.A33	7.47 b-e	65.7 ab	66.7 bcd	23.8 b-f	194.7 abc	97.2 ab	78.2 c-f
404-6×401-9	Pio.A33 × Pac.984	7.11 cde	64.0 bcd	66.3 bcd	23.3 b-f	175.4 de	84.1 c-f	80.0 bc
406-1×403-6	Pio.3012 × Mon.919	6.59 de	63.7 bcd	65.0 d-g	22.1 def	183.5 bcd	93.3 bc	77.8 efg
405-5×402-6	Syn.48 × Mon.949	6.55 de	63.3 cd	65.3 def	24.6 abc	178.3 de	79.9 efg	75.0 h
401-9×402-6	Pac.984 × Mon.949	6.32 e	63.0 cd	64.3 efg	23.4 b-f	180.9 cde	77.3 efg	78.2 c-f
Check	Pio.A33	8.47 ab	64.7 abc	66.0 cde	21.9 ef	182.0 bcd	91.9 bcd	79.8 bcd
Check	SW 4452	8.26 abc	66.7 a	68.7 a	25.0 ab	177.3 de	84.2 c-f	76.3 fgh
Check	Pio.3012	8.08 abc	66.7 a	68.0 ab	22.4 def	165.2 e	89.1 b-e	77.2 efg
Check	Syn. 48	7.86 abc	64.0 bcd	66.0 cde	22.7 c-e	171.3 de	74.4 g	77.9 d-g
Check	Mon.949	7.57 bcd	62.7 cd	64.3 efg	26.7 a	178.3 de	81.6 c-g	77.9 d-g
Check	Mon.919	7.32 b-e	63.3 cd	65.0 d-g	23.9 b-e	176.1 de	88.1 b-f	82.9 a
Mean of top 10 interfamily cross		7.34	63.7	65.2	23.6	182.4	87.5	77.5
F-value ^{1/}		**	**	**	**	**	**	**
CV(%)		10.322	1.9	1.839	5.706	5.327	8.393	1.494

^{1/} ns: non significant, * : significant, ** : highly significant

they were statistically not different.

Evidences from previous studies (Genter, 1976; Landi and Frascaroli, 1993; Rasmusson and Phillips, 1997 and Troyer, 1999) showed that selections in a very narrow base populations were very effective for the improvement of the populations as well as inbred lines per se. The method for composite line improvement used in the present studies is very similar to that suggested by Genter (1976) for population improvement but only 3 S_1 lines were used to form new population of each cycle, aiming to get uniform, high yield and high combining ability composite lines for better hybrid combinations. The method is simply a modification of S_1 and full-sib selection and

therefore it will be referred to as modified S_1 -full sib selection method. Data presented in this study did not show any clear advantage of line selection over the composite line method. More advanced cycles of S_1 -full sib selection are underway to prove the merit of the method as compared to the conventional line selection by pedigree method.

The composite-sibbed lines as proposed by Kinman (1952) is clearly had an advantage over line selection method when time and space are involved. Composite-sibbed lines are ready for final testing without five or six generations of selfing usually practice in the development of inbred lines. In the modified S_1 -full sib selection, composite-sibbed lines can be derived from

Table 5 Grain yields at 15 percent moisture and other agronomic traits of top 10 testcrosses between composite lines of cycle 1 \times KRi 208 and original hybrids at Suwan Farm, Thailand in November 2005 (dry season).

Set numbers	Source of germplasms	Grain Yield (ton/ha)	Days to Anthesis (days)	Days to Silking (days)	Moisture Content (%)	Plant Height (cm)	Ear Height (cm)	Shelling (%)
set 4	Mon.949	8.74 a	62.7 fg	63.3 ghi	24.9 abc	172.5 a-d	84.4	76.1 def
set 3	Pac.984	8.31 abc	65.7 a-d	67.0 a-d	23.8 b-g	165.5 c-g	84.9	78.9 bc
set 11	Syn. 48	7.80 a-d	64.0 c-f	65. d-h	22.9 b-h	163.9 d-g	78.5	74.6 fg
set 5	Mon.949	7.65 a-d	61.7 g	62.7 i	23.8 b-g	168.8 b-g	80.5	76.5 c-f
set 12	Syn. 48	7.44 b-d	63.3 efg	64.7 e-h	22.9 b-g	160.7 efg	77.2	76.3 def
set 17	Mon.919	7.37 b-f	63.0 efg	65. d-h	21.1 h	161.9 d-g	81.9	76.2 def
set 10	Syn. 48	7.34 b-f	62.7 fg	63.0 hi	22.2 fgh	160.5 fg	81.2	77.1 cde
set 15	Pio.3012	7.24 c-g	66.0 abc	67.0 a-d	24.0 b-g	189.9 g	82.3	77.2 cde
set 16	Mon.919	7.20 c-g	63.3 efg	64.7 e-h	21.7 gh	161.9 d-g	83.7	75.3 efg
set 18	Mon.919	7.20 c-g	63.7 efg	65.3 c-g	23.9 b-g	169.3 b-g	85.4	77.3 cde
Check	Pio.A33	8.47 ab	64.7 b-f	66.0 b-f	21.9 gh	182.0 a	91.9	79.8 b
check	SW 4452	8.26 abc	66.7 ab	68.7 a	25.0 ab	177.3 ab	84.2	76.3 def
Check	Pio.3013	8.08 a-d	66.7 ab	68.0 ab	22.4 e-g	165.2 d-g	89.1	77.2 cde
Check	Syn. 48	7.86 a-d	64.0 c-f	66.0 b-f	22.7 c-g	171.3 a-e	74.4	77.9 bcd
Check	Mon.949	7.57 a-d	62.7 fg	64.3 ghi	26.7 a	178.3 ab	81.6	77.9 bcd
Check	Mon.919	7.32 b-f	63.3 efg	65. d-h	23.9 b-g	176.1 abc	88.1	82.9 a
Mean of top 10 topcrosses		7.63	63.6	64.8	23.1	167.5	82.0	76.6
F-value ^{1/}		**	**	**	**	**	ns	**
CV(%)		10.175	1.923	1.921	5.964	3.873	7.455	1.93

^{1/} ns: non significant, * : significant, ** : highly significant

composite sets as used in this study or using the individual S_1 and full-sib of each successive cycle. In addition, S_1 lines may be selfed for one or two additional generations in order to eliminate the undesirable alleles and several desirable sister lines may then be composited to establish the composite-sibbed lines.

CONCLUSION

Line selection combined with early generation testing for combining ability is an effective method. It gave higher average yield of top-10 S_2 testcrosses over the composite

testcrosses. However, statistically, there was no clear advantage of yield between both groups of lines in early generation testcrosses. Besides, the selected S_2 and composite lines showed similar results in diallel cross sets. Visual selection under low-competition environment proved to be a very effective method to identify good combining and relatively high yield lines. However, testcross and diallel cross should be applied for thorough test of combining ability of lines.

Composite lines had clear advantages over S_3 lines in yield, earliness and plant height. The modified S_1 -full sib selection for the improvement of composite lines is a flexible

Table 6 Grain yields at 15 percent moisture and other agronomic traits of interfamily diallel hybrids of composite lines (cycle 1) and original hybrids at Suwan Farm, Thailand in November 2005 (dry season).

Composite ^{2/} × composite	Source of germplasms	Grain Yield (ton/ha)	Days to Anthesis (days)	Days to Silking (days)	Moisture Content (%)	Plant Height (cm)	Ear Height (cm)	Shelling (%)
2 × 4	Pac.984 × Mon.949	9.33 a	65.0 c-h	66.3 b-e	22.9 b-e	190.1	95.3 abc	78.8 b-e
4 × 7	Mon.949 × Pio.A33	9.18 ab	63.7 g-j	64.6 def	24.4 bc	181.4	92.9 a-d	78.5 b-e
2 × 15	Pac.984 × Pio.3012	7.98 c-f	65.7 a-f	66.3 b-e	19.3 f	182.9	91.9 b-e	78.9 b-e
4 × 11	Mon.949 × Syn. 48	7.98 c-f	63.0 ij	64.0 f	23.0 b-e	184.9	89.3 b-f	77.5 de
7 × 17	Pio.A33 × Mon.919	7.62 c-h	63.7 g-j	65.0 def	21.4 ef	177.6	95.7 ab	77.9 cde
11 × 15	Syn. 48 × Pio.3012	7.20 d-i	65.3 b-g	66.3 b-e	22.8 c-e	187.5	100.5 a	77.6 de
2 × 17	Pac.984 × Mon.919	7.06 e-i	66.0 a-e	66.7 a-d	20.5 ef	189.5	86.3 e-g	77.3 de
7 × 15	Pio.A33 × Pio.3012	6.97 e-i	66.7 abc	68.3 ab	21.4 ef	169.7	87.1 c-g	77.8 de
4 × 15	Mon.949 × Pio.3012	6.86 f-i	64.3 e-j	65.0 def	23.1 b-e	186.5	92.4 a-e	77.8 de
15 × 17	Pio.3012 × Mon.919	6.75 ghi	63.3 i-j	65.0 def	21.0 ef	175.6	89.1 b-f	81.2 abc
Check	Pioneer A33	8.47 abc	64.7 d-i	66.0 d-f	21.9 def	182	91.9 b-e	79.8 a-d
Check	Suwan 4452	8.26 a-d	66.7 abc	68.7 a	25.0 ab	177.3	84.2 efg	76.3 e
Check	Pioneer 3012	8.08 b-e	66.7 abc	68.0 abc	22.4 c-f	165.2	89.1 b-g	77.2 de
Check	Syngenta NK 48	7.86 c-g	64.0 f-j	66.0 d-f	22.7 c-f	171.3	74.4 h	77.9 cde
Check	Monsanto 949	7.57 c-h	62.7 j	64.3 ef	26.7 a	178.3	81.6 fgh	77.9 cde
Check	Monsanto 919	7.32 c-i	63.3 hij	65.0 def	23.9 bcd	176.1	88.1 b-g	82.9 a
	Mean of top 10 interfamily cross	7.69	64.7	65.8	22.0	182.6	92.1	78.3
	F-value ^{1/}	**	**	**	**	ns	**	*
	CV(%)	9.449	1.825	1.941	5.827	7.565	5.779	2.557

^{1/} ns: non significant, * : significant, ** : highly significant

^{2/} Crosses between two sets of composite lines.

method which can be applied to improve the composite as well as inbred lines. However, further investigation is required to prove its merit for the construction of early generation hybrids as well as for the improvement of inbred lines.

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