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Alternate S_1 and Diallel Cross Selection for High Yield and High Combining Ability Maize (*Zea mays* L.) Inbred

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ABSTRACT

Five S_2 maize families and 5 plants per family were derived from Agronomy Department, Kasetsart University program. They were selected by two cycles of S_1 selection in R-49 grouped replicated honeycomb (HC) design with equilateral triangle of side 0.866 m and 40 replications. The 25 S_2 plants were designated as line number 1 to 25. Selection was continued by bulk family pedigree method until S_4 lines were obtained. Simultaneously, remnant S_2 seeds were diallel crossed within each family set and the top intra-family hybrid (F_1 C_0) of each set was self pollinated to obtain S_1s which subsequently diallel crossed to obtain intra-family hybrids of cycle-1 (F_1C_1). However, only S_1s of the top F_1 C_0 of the first top 3 family sets were used. Moreover, the top F_1 C_0 of each set were diallel crossed and testcrossed to their corresponding S_4 sister lines to obtain inter family and intra-family testcross hybrids, respectively. All types of hybrids and S_4 lines were evaluated for their yielding ability and combining ability at the National Corn and Sorghum Research Center, Thailand.

Intra-family hybrids of the cycle-0 and cycle-1 were at par with the common check for grain yield. However, the yield of one intra-family testcross hybrid of the second set of cycle-0 was significantly higher than that of the common check, while two inter-family hybrids of cycle-0 were relatively high yield but not significant from the single cross, Agron2029. Yield of most S_4 lines from pedigree selection were relatively high and could be used for commercial seed production. The methods fitted to the additive gene effect model and effectively identified high yielding early generation hybrids which could be used as source of either recycled single cross hybrids or modified double cross hybrids. It is expected that this research will provide a guide line for appropriate selection intensities for inbred line development in maize. The method is the alternate S_1-diallel cross selection for high yield and high combining ability inbreds in highly selected materials for the production of hybrids which adapt to wide ranges of plant densities.

Key words: family selection, diallel, maize, hybrid

INTRODUCTION

The pure line method of maize breeding has been the basic breeding method used in developing lines and hybrids since the suggestion of Shull in 1909. Modifications of the pure-line method of breeding have been made during the past 80 years as information, techniques, and equipment became available. Heterosis is the basis of the modern cultivars utilized in maize. The primary aim of maize breeders is to develop populations and inbred lines that can be crossed to form superior hybrids.

The most often used plant breeding method

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for inbred line development in maize is the pedigree method. It emphasizes knowing the materials with complementary traits and keeping records that show family relationship. The pedigree method was finally used for final development of the inbreds and the pedigree method is still the most popular breeding method for the improvement of inbred (Troyer, 2001).

Genetic and environmental factors are associated in a process of developing cultivars with high and stable crop yield potential in plant breeding. The plant-to-plant interference with the equal sharing of growth resources caused by genetic and acquired differences and the clarification of its negative roles on two important aspects; crop yield and selection efficiency. The first component comprises genes ensuring high yield potential per plant. The second component comprises genes controlling tolerance to the biotic and abiotic stresses (Fasoula and Fasoula, 2002).

Selection is ultimately the differential production of genotypes. The propose and the critical feature of artificial selection is to choose from a group of individuals that will be allowed to reproduce to make selection as effective as possible from a given intensity. Investigation of inbred line development have focused mainly on refinement of methods and techniques used to improve performance of inbred line per se and on the lines for hybrid combinations while few studies directly addressed optimal use of available resources required to develop and produce inbred lines. Therefore, knowledge of optimum intensity of selection and number of individuals within family to be selected and retained during inbred line development is crucial in maize breeding. Differences in grain yield between older and newer maize hybrids were shown to be a function of plant population density (Duvick, 1984). The necessity of higher plant densities for optimal productivity of modern maize hybrids led Troyer and Rosenbrook (1983) to suggest that selection under higher plant densities was a means to improve grain yield of maize. Conversely, for the same objective, Duvick (1997) suggested to select under lower plant density environment (1 plant/m^2). Gain from selection can be increased for any recurrent selection method by increasing selection intensity which is the ratio of lines selected for inter-mating to the number of lines evaluated (Sprague and Eberhart, 1977).

The history of inbred line development and changes that have taken place the onset of the inbred-hybrid concept are discussed by Hallaur (1990 and 1992). A good hybrid-testing program is essential to recognize the best inbred and to identify their relative strengths and weakness. Elite inbreds are the best source materials for future progress and crucial for hybrid production (Troyer, 2001).

High yield and high combining ability inbreds are very crucial for commercial seed production and hybrid performances. Goulas and Lonnquist (1976) proposed the combined half-sib and S_1 family selection in maize composite population. However, Coors (1988) indicated that simultaneous improvement of both inbred and testcross performance may be difficult. In order to improve the efficiency of the combined selection as proposed by Goulas and Lonnquist (1976) the alternate S_1 and diallel cross selection in the absence of competition and stress, respectively was designed for the selection of high yield and high combining ability inbred. The present study was conducted to verify the effectiveness of the alternate S_1-diallel cross selection for inbred performance per se as well as their cross performances either intra- or inter family crosses.

MATERIALS AND METHODS

Five S_2 maize families and 5 plants per family were derived from Agronomy Department, Kasetsart University program (Samphantharak and Yavilads, 2002). The pedigree of 5 S_2 families are Ag17/Ag25//Ag22/Ag27, Ag27/Ag26 //Ag11/Ag

27, Ag18/Ag25//Ag18/Ag26,Ag25/ Ag24//Ag27/ Ag6 and Ag27/Ag26//Ag18 /Ag26. They were selected by two cycles of S_1 selection in R-49 grouped replicated honeycomb (HC) design with equilateral triangle of side 0.866 m and 40 replications as described by Fasoulas and fasoula (1995). The 25 S_2 plants were designated as line number 1 to 25. Selection was continued by bulk family pedigree method until S_4 lines were obtained.

Remnant seeds of 25 S_2 lines were planted and diallel crossed within each family set and the resulted 50 intra-family hybrids designated as F_1C_0 (10 hybrids from 5 lines of each family set) were tested for their yielding ability and some other agronomic traits in separated trials in adjacent areas using a randomized complete block design (RCBD) with 4 replications, 4 row plots of 5 m long and 0.75 × 0.25 m plant spacing. Single cross hybrid, Agron2029 was included as common check for all trials. Five plants in the border rows of each hybrid were self pollinated and harvested separately.

Remnant seeds of F_1C_0 were planted in a non-replicated HC and selected plants were diallel crossed (F_1 C_0 x F_1 C_0) to obtain 10 inter-family cross hybrids of cycle-0. Simultaneously, top F_1C_0 each of the first 3 sets were testcrossed to their corresponding 5 S_4 sister lines from pedigree selection to obtain 15 intra-family testcross hybrids. Moreover, 5 S_1 lines from each 3 selected F_1C_0 were planted in non replicated HC and selected plants were diallel crossed within each family set ($S_1C_1xS_1C_1$) to obtain 30 intra-family cross hybrids of cycle-1 (F_1C_1). All types of hybrids were evaluated together in a split plot in RCBD with 4 replications, 1 row plots of 5 m long and 0.75 × 0.25 m plant spacing. Single cross hybrid, Agron2029 was included as a common check. Similarly, S_4 lines from pedigree selection were evaluated in separated split plot design.

All experiments were conducted in 2001 to 2003 at National Corn and Sorghum Research Center, Suwan Farm, in the Nakhon Ratchashima province (14^0 30’ N, 101^0 30’ E, and 356 m asl.) in Thailand.

RESULTS AND DISCUSSION

The derived 25 S_2 lines were divided into five within family sets; set-1 (1-5), set-2 (6-10), set-3 (11-15), set-4 (16-20) and set-5 (21-25). The top intra-family hybrids of cycle-0 (F_1C_0) one from each set were presented in Table 1. All of the top yielding intra-family hybrids came from lines which possessed high general combining ability (ranked 1 and 2) within set, except the top hybrid of set-2 which derived from lines with ranked 1 and 3 in general combining ability within set. Statistically, yield of the top inrta-family hybrids from each set were not different from the single cross, Agron 2029. Other selected agronomic traits were also very similar to it. Since all of S_2 lines derived from two cycle of S_1 selection under nil-competition environment in honeycomb design. The results revealed that after two cycles of selection for inbred per se under nil-competition environment, selected inbreds still possessed the ability to render intra-family hybrids, which could adapt to high crop density.

Table 2 presented the top intra-family hybrids of cycle-1 (F_1C_1). Each hybrid derived from 2 S_1 sister lines of the corresponding intra-family hybrids F_1C_0 in Table-1. The performances of selected F_1C_1 were more or less the same as Agron2029. Therefore, the performances of early generation hybrid could be retained by alternate S_1 selection for inbred per se under nil-competition environment and testing for their combining ability under high crop density at the end of each cycle. This method is practically a modified pedigree selection for recycled inbreds and recycled hybrids. It required only 2 growing seasons per cycle, (1) testing the F_1s under high crop density and selfing the border rows, (2) planted the S_1s from the best cross under nil-competition environment and diallel

Table 1 Grain yields at15 percent moisture and other agronomic traits of top intra-family hybrid (S_2 x S_2) of each family set of cycle-o planted at Suwan Farm in June, 2002 (dry season).

Set #	Pedigree * (F_1 C_0)	Grain yield	Anthesis	Silking	Plant height	Ear height	Moisture	Shelling
		t /ha	days		cm		%	
1	L1/L2	8.65[ab]	58	60	151	77	21.26	75.71
2	L7/L9	8.71[ab]	60	62	174	110	24.14	75.8
3	L11/L13	8.01 [b]	59	61	150	79	21.92	74.27
4	L17/L19	7.62 [b]	60	62	168	92	22.56	75.55
5	L22/L25	7.47 [b]	61	63	164	101	24.87	70.77
Ch	Agron 2029	9.49 [a]	58	60	170	82	24.57	76.37
	Mean	8.32	59	61	163	90	23.22	74.75
	% CV	9.58	1.99	1.95	5.08	6.59	11.20	3.58

* Pedigree of top intra-family hybrids, F_1 C_0 (S_2 x S_2) of each family set, 10 hybrids per set.

Table 2 Grain yields at15 percent moisture and other agronomic traits of top intra-family hybrid (S_1 x S_1) of each family set of cycle-1 planted at Suwan Farm in April, 2003(dry season).

Set #	Pedigree (F_1 C_1)	Yield	Anthesis	Silking	Plant height	Ear height	Moisture	Shelling
		t /ha	Days		cm		%	
1	L1/L2	6.85 [a]	54	56	193	113	22.83	75.83
2	L7/L9	5.53 [b]	53	55	188	115	24.97	79.42
3	L11/L13	6.37 [ab]	54	56	172	89	26.35	75.62
Check	Agron2029	6.82 [a]	54	56	179	97	23.91	76.18
	Mean	6.39	54	56	183	104	24.52	77.51
	% CV	18.32	2.11	2.21	4.36	7.39	10.04	8.52

* Pedigree of top intra-family hybrids, F_1 C_1 (S_1 x S_1) of each family set, 10 hybrids per set.

crossed the S_1 sister lines to obtain F_1s for testing under high crop density in the following cycle. The yield of inbred per se should be improved with higher degree of homozygosity as the selection cycle advanced while retained or even improved the performance of recycled hybrid over the original hybrid. Moreover, the method can also be used for direct improvement of modified double cross hybrid if two complementary single cross hybrids were simultaneously improved and crossed between the two populations.

Table 3 presented yields of top 10 hybrids from different crossing status; 30 intra-family hybrids ($S_1 C_1$ x $S_1 C_1$) of the first 3 sets, 15 intra-family testcross hybrids (S_4 x F_1C_0) of the first 3 sets and 10 inter-family hybrids (F_1C_0 x F_1C_0) from diallel cross of 5 F_1C_0 in Table 1. Unexpectedly, one intra-family testcross hybrid

Table 3 Grain yields at 15 percent moisture of top 10 hybrids from the different sets of crosses, planted at Suwan Farm in April, 2003 (dry season).

Rank order	Crossing status	Pedigree*	Yield	Anthesis	Silking	Plant height	Ear height
			t /ha	days		cm	
1	Intra-fam. testcross	S_4 L8 / F_1 C_0 Set2	8.38 [a]	53	54	182	112
2	Inter fam. cross	F_1 C_0 Set4 / F_1 C_0Set2	7.65 [ab]	53	55	183	112
3	,,	F_1 C_0 Set4 / F_1 C_0Set3	7.65 [ab]	53	55	178	100
4	,,	F_1 C_0 Set2 / F_1 Set1C_0	7.40 [a-c]	53	54	175	106
5	Intra fam. cross	S_1 C_1 Set1 / S_1 C_1 Set1	6.85 [b-d]	54	56	193	113
6	Inter fam. cross	F_1 C_0 Set4 / F_1 C_0 Set1	6.40 [b-f]	53	55	178	94
7	Intra fam. cross	S_1 C_1 Set3 / S_1 C_1 Set3	6.35 [c-g]	54	56	172	89
8	,,	S_1 C_1 Set3 / S_1 C_1 Set3	6.33 [c-g]	54	56	174	100
9	,,	S_1 C_1 Set3 / S_1 C_1 Set3	6.28 [c-h]	53	55	173	98
10	Inter fam. cross	F_1 C_0 Set3 / F_1 C_0 Set2	6.25 [c-h]	53	55	187	116
	Check	Agron2029	6.80 [b-e]	54	56	178	96
	Mean		6.11	53	55	179	103
	% CV		18.64	2.05	2.1	4.91	7.05

* Top-10 of 55 hybrids including; 30 intra-family hybrids (S_1C_1 x S_1C_1), 15 intra-family topcross hybrids (S_4 x F_1C_0) and 10 inter family hybrids (F_1C_0 x F_1C_0).

(S_4L_8/ F_1C_0 set 2) was significantly higher yield than Agron2029. The rest of the top 10 hybrids were 5 from inter-family crosses and 4 from intra-family crosses. Therefore over dominance was not important for grain yield in these breeding materials. Although, they were not significantly different from Agron2029, yields of the three inter-family hybrids were relatively high. Since additive gene action is a predominant gene action therefore selection for specific combining ability should be effective for improving general combining ability. The results of this study was well agreed with the result revealed by Russel *et al.* (1973). The intra-family crosses of set- 3 came from a very narrow genetic base of inbred lines originated from commercial hybrids, Pioneer 3012 and Pioneer 3013 (Samphantharak and Yavilasd, 2002). However, 3 of them were among the top-10 hybrids. S_2L_8 line in set-2 was the second lowest general combining ability within its set but S_4L_8 rendered the significant high yield in intra-family testcross hybrid (S_4L_8/F_1C_0 set2). Therefore, it possessed a specific combining ability with its related high general combining tester (L7/L9). According to the present breeding schemes, degree of homozygosity of all lines should be higher in advanced selection cycles and eventually become homozygous lines. Their combining ability should also be improved accordingly.

Yield of selected S_4 from pedigree selection which corresponded to original S_2 lines of which involving parents of F_1C_0 in Table 1 and S_4L_8 of intra-family testcross hybrid in Table 3 were presented in Table 4. Yield of most selected S_4 lines was relatively high except S_4L_{11} and S_4L_{19}. It is interesting that not a single hybrid of set-5 was included in top-10 hybrids in Table 4 eventhough yield of S_4 lines of set-5 (L_{22} and L_{25}) was among

Table 4 Grain yields at 15 percent moisture of selected S_4 lines from pedigree selection which corresponded to S_2 lines in Table1 and S_4L8 in Table3 planted at Suwan Farm in April 2003 (dry season).

Set #	S_4 Line	Yield	Anthesis	Silking	Plant height	Ear height	Moisture	Shelling
		t /ha	days		cm		%	
1	S_4 L1	4.92 ^{ab}	53	55	169	92	28.99	76.89
	S_4L2	2.61 $^{d-g}$	55	57	143	75	23.98	72.45
2	S_4L7	4.64 ^{ab}	53	55	173	102	27.51	71.67
	S_4L9	3.13 $^{c-f}$	57	59	160	102	28.48	65.35
	S_4L8	3.63 a-e	54	56	178	91	28.71	70.92
3	S_4L11	1.07 ^{h}	58	60	136	74	24.93	60.05
	S_4L13	3.97 $^{a-d}$	56	58	131	79	27.09	73.39
4	S_4L17	4.15 $^{a-c}$	54	56	161	90	28.45	80.12
	S_4L19	1.93 $^{f-h}$	57	60	170	95	28.58	70.62
5	S_4L22	4.82 ^{ab}	54	56	171	91	27.28	73.85
	S_4L25	4.61 ^{ab}	54	56	166	94	27.23	68.17
	Mean	3.59	55	57	158	90	27.23	71.26
	% CV	23.96	2.06	1.83	7.71	7.10	7.5	7.5

the highest of S_4 lines. Since most of quantitative traits are controlled by additive genes and thus high yield inbreds should also have high combining ability. However, additive gene effect may come from genes within locus as well as additive effect between loci (Falconer, 1960). Therefore, not only high yield inbred is required but must also retain the genetic diversity among both parents. Therefore, an effective breeding scheme should include both selection for inbred per se and systematic testing for their combining ability in order to retain high yield inbreds and maximize heterotic effect of both parents which are the requirement for good performance hybrid and production of commercial hybrid seeds.

CONCLUSION

Eventhough, pedigree selection is still a widely used method for the improvement of inbreds either for direct use or for hybrid combinations, its effectiveness is limited by fast fixation of genes due to continuous selfing nature of the method. High yield inbred alone does not guarantee for good performances in hybrid combinations. Genotype and environment interaction is also a matter of concern for effectiveness of selection. Plant normally expresses its genotypic potential more effectively under nil-competition environment where all factors required for biological function are adequate. However, inbred selected under nil-competition environment may not adapt under stress condition, which is the cultivation environment. Besides, high yield inbred does not ensure their performances in hybrid combinations. Therefore, a good breeding scheme is needed for selection of inbred line performance per se under the conditions which allow highest expression of genotypes as well as testing for their performance in hybrid combinations. Alternate S_1

and diallel cross selection of inbreds and their hybrid combinations under nil and stress condition respectively, should be an effective breeding scheme for selection of high yield inbreds and hybrids which could adapt under stress conditions. The method has proved its effectiveness in identifying early generation hybrids and retained the hybrid performances in advanced generations. However, instead of using the breeding scheme for the improvement of inbred lines, the method can be used to maintain or to continuously improve commercial inbreds and use the recombinant of sister lines of each selection cycle as breeder seeds. The method can also be used for the improvement of population per se if diverse lines were selected for recombination in each cycle.

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