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S_1 Selection in Honeycomb Design for the Improvement of High Yield Maize (*Zea mays* L.) Inbreds and Hybrids

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ABSTRACT

Selection within Syn1 population of maize resulted in genetic equilibrium of selected population within 1 or 2 cycles of selection. High yield level could be obtained in a faster rate when improvement was applied in a narrow base population from adapted germplasm as compared with broad base population from unadapted germplasm. S1 and testcross selection which selected for high yield and high combining ability inbreds, respectively required 3 planting seasons per cycle. In order to improve the efficiency of selection, alternate S1 and diallel selections which required only 2 planting seasons per cycle was proposed. Inbred extraction from heterogeneous population for high yield inbreds under competitive environment by pedigree selection rendered the inconsistent results. Therefore, inbred selection under nil-competition to ensure full expression of genotypes in early generations should increase the efficiency of pedigree selection for high yield inbreds. Good hybrids could derive from high yield and/or high combining ability inbreds. However, high yield inbreds are preferable over the high combining ability but low yield inbreds, especially when commercial single cross hybrid is the ultimate goal of the program.
Key words: corn, hybrid, honeycomb, S_1 selection

INTRODUCTION

Pedigree selection is generally a selection method widely used for inbred improvement. However, in order to purify the inbreds, every plant improvement method is normally followed by pedigree selection (Troyer, 2001). In addition, pedigree selection is suitable only for the detail improvement of few desirable traits of existing lines. It is a time consuming processes to bring several desirable traits from other lines into the new improved line. Eberhart *et al*. (1995) suggested that population improvement should be implemented to improve vast amount of breeding materials before pedigree selection was employed. In the past decades, population improvement methods have been refined to fit the theoretical change of breeding concepts. The most widely used testcross and S_1 selections which emphasized on the combining ability and inbred performance *per se* of selected lines, respectively rendered the inconsistent results. Differences in breeding materials, environments, accuracy of the collected data and experiences of breeders may be the causes of the inconsistent results (Genter and Eberhart, 1974). However, Weyhrich *et al*. (1998) conducted the experiment by using the same breeding materials to test 7 selection methods of population improvement and concluded that if yield and other desirable traits were simultaneously selected, S_1 and S_2 selections were superior to the other methods employed. Moreover, cultural

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practices also play the important role for the full expression of genotypes, minimize environmental variation and hence increase selection efficiency. Troyer (1996) suggested that selection for stress tolerant lines should be done under densely grown condition. Therefore, selected lines should express high yield per unit area however they might give low yield per plant (Fasoula, 1990). On the contrary, for the full expression of lines, selection of inbreds under nil-competition environment and tested the hybrid combinations under desired plant densities was demonstrated by Tokatlidis *et al*. (2001). The method rendered lines with high yield per plant as well as per unit area which is a requirement for commercial single cross hybrid.

The purposes of this study were to : 1) evaluate the efficiency of S_1 selection for population improvement of maize under nil-competition as suggested by Fasoulas and Fasoula (1995) and 2) improve inbred performance *per se* for commercially producible single cross hybrid.

MATERIALS AND METHODS

The experiment was conducted at National Corn and Sorghum Research Center, Nakhon Ratchasima, Thailand from December, 1999 to July, 2003.

Ten inbreds from Agronomy Department, Kasetsart University program namely : Ag17 and Ag18 (Pioneer 3012); Ag6, Ag25 and Ag26 (Pioneer3013); Ag27 (G5445A); Ag11 and Ag28 (SW3853); Ag24 (Uni-h9728) and Ag22 (Cargill919) were diallel crossed to generate AgC0Syn1 (cycle-0). The derived 45 F1s were separately planted and self-pollinated to obtain 45 C0S1. In order to facilitate experimental arrangement,4 additional C0S1 were added and the 49 C0S1 were planted in R-49 grouped replicated honeycomb design, 40 replications. For honeycomb arrangement, row spacing = 0.866 xplant spacing (Fasoulas and Fasoula, 1995). Therefore, with row spacing of 0.75 m, plant spacing is 0.866 m. Moving circle selection with selection intensity of 14.3 % was applied. Simultaneously, 1 out of 7 plants within row or 14.3 % was selected (visual grid selection). All selected plant were self-pollinated to obtain C0S2. Ten C0S2 corresponded to the top-10 selected C0S1 by moving circle selection were harvested separately. They were planted and then diallel crossed to generate the AgC1Syn1 (cycle-1) and the processes were repeated to generate AgC2Syn1(cycle-2). The remnant seeds of C0S2, C1S2 and C2S2 were simultaneously planted, ear-to-row and 3 to 5 ears per row were self-pollinated. At harvest time, selected ears from each row were separately bulked. The bulk family pedigree selection was continued until C0S6, C1S4 and C2S2 were obtained.

Two selected C0S5 corresponded to the 2 highest general combining ability C0S2 were diallel crossed with 10 C1S2. The bulk seeds of the resulted 66 F1s was designated as AgC2Syn1-Sem. (semi-open end population, cycle2-Sem.) Simultaneously 10 selected C0S5 were also diallel crossed to generate a series of C0S5x C0S5 hybrids.

All yield trials were planted in adjacent areas including : 10 original inbreds (Ag-)and 10 C0S5 : 45 C0S5x C0S5 and 4 commercial hybrids, Pioneer3013, CP989, Syngenta NK 45 and Cargill919 :AgSyn1- populations, cycle-0, cycle-1, cycle-2, cycle-2-Sem. and 2 check populations, SW1C12 and SW5C4 : and 10Ag-, 10C0S6 and 10C1S4. Plant spacing of all experiments was 0.75 m. × 0.25 m., 5 m. row and all yield trials were planted is randomized complete block design, 4-row plot and 4 replications. Duncan's multiple range test was employed for test of significant. All cultural practices were followed the procedure regularly used at the National Corn and Sorghum Research Center.

RESULTS AND DISCUSSION

Yield of populations, cycle-1 and cycle-2 were significantly decreased from cycle-0 (Table1). Statistically, yield of cycle-1 and cycle-2 were not different. Selection in Syn1 populations led to the declining of gene frequencies of the low combining ability lines and resulted in equilibrium of gene frequencies of selected population after few cycles of selection (Samphantharak and Yavilads, 2002). Progress of selection in the later generation expected to be low because of selection was applied to the high yield lines of narrow genetic variation. However, yield of cycle-2 was increased although it was not different from cycle-1. There were non-significant change for other selected traits except lower grain shelling percentage and higher disease resistance of the later cycles. Visual selection for bigger ears was accounted for the lower grain shelling percentage of cycle-1 and cycle-2 and led to the lower yield of the later two populations. Therefore, selection in the following cycle should be emphasized more on higher grain shelling percentage. Honor *et al*. (1969) found that yield of the first few cycles of selection were dropped and gradually increased in the later cycles and surpassed the cycle-0 after 5 cycles of selection.

The semi-open end population (cycle-2-Sem.) yielded statistically the same as cycle-1 and cycle-2. The results indicated that selection within the same original breeding materials by S1 and pedigree selections resulted in lines of similar alleles. Therefore, no heterosis between groups of S2 lines from cycle-1 and C0S5 from pedigree selection. The selected C0S5 which were included in cycle-2-sem were based on combining ability of corresponding C0S2 which was not necessary to be the same as of C0S5 because of recombination of genes in segregated lines. Moreover, separately tested for combining ability within each group of lines from the same origin might end up with the accumulation of similar alleles. The direct testing for combining ability by testcross between cycle-1 and the 10 C0S5 should identify a complementary alleles better than the indirect testing for combining ability as used in this experiment. The complementarly lines should improve yield of cycle-2-Sem and increase genetic variability of population for further improvement.

Table 1 Yield and other selected trailts of AgSyn1-populations tested at the National Corn and Sorghum Reseach Center.

Selection cycles	Grain [1] yield	Percent to SW1-C12	50% silking	Shelling	Moisture	Plant hight	Ear hight	Foliar dis.[2]
	kg./ha.	%	days	……….%	…………	……cm	………	0-5
C0	4,768 a	108	54 a	82 a	29 a	176 b	96 b	1.25 ab
C1	4,293 b	97	54 a	79 b	29 a	174 b	100 ab	0.50 b
C2	4,318 b	98	53 a	78 b	29 ab	177 b	103 ab	1.00 ab
C2-Sem.	4,362 b	99	54 a	79 b	29 ab	173 b	100 ab	1.00 ab
Check								
SW1-C12	4,381 b	100	54 a	78 b	28 ab	191 a	103 ab	0.75 ab
SW1-C4	4,406 b	100	54 a	79 b	29 b	196 a	105 a	1.5 b
Mean	4,425	_	54	79	29	181	101	1.00
% CV	3.03	_	1.32	1.28	2.07	3.3	4.62	54.77

[1] Grain yield was measured at 15 % moisture.
[2] Rating of disease resistance from 0 to 5, high to low, repectively.
– Means followed the same letter are not significant difference,

Yield and other selected traits of cycle-1 and cycle-2 as well as SW1C12 and SW5C4 were similar although they were from different groups of original breeding materials. The results indicated that all populations which were selected at the same location accumulated similar alleles by natural selection. All AgSyn1- populations derived from commercial hybrids while SW1C12 derived from very diverse exotic germplasm and SW5C4 was descended from locally improved breeding materials. Therefore, unless there is a need for specific desired trait, breeding materials should come from highly adapted materials. It has been proved that high adaptability and less diverse germplasm is more useful than highly diverse but low adaptability germplasm (Troyer, 1999).

Yield and other selected traits of original inbreds (Ag-), C0S6 and C1S4 were presented in Table 2. The average yield of Ag-(S6), C0S6 and C1S4 were 3,436 kg/ha and increased to 4,247 kg/ha and 4,390 kg/ha, respectively. The results indicated that the newly improved inbreds especially C0S6 accumulated more favorable genes with less inbreeding depression than Ag-(S6) and thus expressed higher yield. By average, magnitude of expression of other selected traits did not change except grain shelling percentage. The results corresponded to the expression of corresponding traits of each original population where the inbreds came from (Table 1 and 2).

The 10 selected C0S5 were designated as Ag201 to Ag210 as presented in Table3. Yield of most C0S5 as compared to the corresponding parent lines were skewed to the higher parents because of visual selection toward inbred performance *per se*. However, individually, Ag201 and Ag207 showed transgressive segregation over upper limit of the parents but Ag209 and Ag206 showed transgressive segregation over lower limit of the parents while Ag202 and Ag204 had lower average than midparents. Therefore, visual selection was inaccurately identified high and low yield lines from densely grown of segregated population. Moreover, under the competitive condition among different genotypes, the high competitive and low yield line could out yield the high yield but low competitive line (Fasoulas and Fasoula, 1995). However, Ag201 and Ag203 were outstanding lines for yield *per se* while yield of other lines were statistically the same except Ag209 which was significantly lower yield than other lines. In order to improve the efficiency of visual selection, selection under nil-competition which allows full expression of genotypes up to S_3 generation should help to minimize the competitive effect between different genotypes. Selection in later generation could be done under densely grown condition to open the chance of selection for density – independent lines (Tokatlidis *et al*., 2001).

Yield of top –10 single crosses (Co S5 × Co S5) including commercial hybrids except CP989 were not statistically different (Table 4). Theoretically, yield of F_1 is equal to yield of mid parent plus heterosis (F_1 = midparent + heterosis). Therefore, good hybrids must come from high midparent and/or high heterosis. According to the theoretical formular, midparent has negative correlation with heterosis and therefore, parents of a good hybrid must be the ones that have the best balance of the two factors as clearly demonstrated by hybrids number 1 to 5 in Table 4. However, high yield parents are needed for commercial hybrid seed production.

To extend the finding of Tokatlidis *et al*. (2001) and combining ability concept, a good population improvement method should accurately identify high yield and high combining ability lines. The diallel series of hybrids should be tested for their yielding ability under competitive environment for high yielding per area and plants in the border rows were simultaneously self pollinated. The S_1 from top yield hybrids (5 to 10 families) then planted under nil – competition in honeycomb arrangement for full expression of genotypes and only good performance S_1 plants

Table 2 Yield and other selected traits of 10 original inbreds, 10 S6C0 and 10 S4C1 tested at the National Corn and Sorghum Reseach Center.

No.	Original inbred	Grian yield 1/ (kg/ha)	Moisture ..... %	Shelling ..... %	Inbred (S6C0)	Grian yield 1/ (kg/ha)	Moisture ..... %	Shelling ..... %	inbred (S4C1)	Grian yield (kg/ha)	Moisture ..... %	Shelling ..... %
1	Ag27	4,283 e-h	14 fg	81 a-d	Ag201	6,267 a	17 ab	80 b-e	Ag307	5,718 ab	16 a-e	82 a-d
2	Ag24	4,239 e-h	17 a	78 d-I	Ag206	5,657 a-c	16 c-f	78 c-I	Ag303	5,718 a-c	15 fg	74 I-L
3	Ag26	3,865 f-k	15 fg	82 a-d	Ag203	4,910 c-e	16 c-f	81 a-d	Ag302	5,337 b-d	16 a-c	77 d-j
4	Ag11	3,844 f-k	14 g	80 b-f	Ag204	4,664 d-f	15 d-g	73 j-m	Ag308	4,829 de	15 d-g	80 b-g
5	Ag6	3,817 g-k	15 fg	83 ab	Ag205	4,256 e-h	16 a-c	71 Lm	Ag304	4,659 d-f	14 g	78 c-I
6	Ag18	3,311 j-l	17 a-c	79 c-h	Ag207	4,116 e-j	16 a-e	83 a-c	Ag310	4,248 e-h	17 a	75 h-L
7	Ag25	3,190 k-m	15 fg	83 a-c	Ag208	3,504 h-l	15 fg	80 b-e	Ag301	4,158 e-I	15 d-g	75 g-L
8	Ag17	2,834 l-n	15 d-g	85 a	Ag210	2,465 mn	15 e-g	68 m	Ag306	4,105 e-j	16 a-d	76 f-L
9	Ag28	2,691 l-n	15 d-g	81 a-d	Ag209	2,386 m-o	16 c-f	76 e-k	Ag309	3,389 I-l	17 a-c	72 k-m
10	Ag22	2,283 no	16 c-f	77 e-j	Ag202	poor germination			Ag305	1,593 o	15 fg	73 j-m
	Mean	3,436	15	81	Mean	4248	16	77	Mean	4390	16	76
	....	....	....	........Check	Ag20	4,563 d-g	16 b-f	79 b-h	....	....	....	....
	....	....	....	....	LSD(0.05)	827	1	4	....	....	....	....
	....	....	....	....	%CV	15	5	4	....	....	....	....

1/ Grain yield was measured at 15 % moisture.

– Means followed the same letter are not significant difference,

Table 3 Yield of 10 S5C0 designated as Ag201 to Ag210 and their parent lines tested at the National Corn and Sorghum Reseach Center.

No	Inbred code	Pedigree Inbred 1/inbred 2	Original parent	Grain yield [1/]	Yield of original inbreds		
					Inbred 1	Inbred 2	Mean
				..........................kg./ha.........................			
1	Ag201	Ag17/Ag27	Pion3012/G5445	5,659 a	1,943	4,877	3,410
2	Ag202	Ag17/Ag27	Pion3012/G5446	3,267 de	1,943	4,877	3,410
3	Ag203	Ag17/Ag27	Pion3012/G5447	4,762 a-c	1,943	4,877	3,410
4	Ag204	Ag22/Ag27	Carg919/G5445	3,527 de	2,909	4,877	3,893
5	Ag205	Ag22/Ag27	Carg919/G5445	3,893 b-e	2,909	4,877	3,893
6	Ag206	Ag27/Ag26	Pion3013/G5445	3,056 e-g	3,486	4,877	4,182
7	Ag207	Ag17/Ag25	Pion3012/Pion3013	3,745 de	1,943	3,238	2,591
8	Ag208	Ag17/Ag25	Pion3012/Pion3013	3,015 e-g	1,943	3,238	2,591
9	Ag209	Ag25/Ag24	Pion3012/Uni9728	2,247 f-h	3,238	4,113	3,676
10	Ag210	Ag11/Ag27	SW3853/G5445	3,759 c-e	2,219	4,877	3,548
			Mean	3,693			3,455
			% CV	20.59			

[1/] Grain yield was measured at 15 % moisture.
– Means followed the same letter are not significant difference,

were diallel crossed for the following selection cycle. The method is essentially alternate S_1 – diallel selections which required only two planting seasons per cycle and allows for the selection of inbred performance *per se* as well as their combining ability in hybrid combinations, simultaneously. While S_1 selection and testcross selection were designed for the selection of inbred performance *per se* and combining ability of selected lines, respectively and each method required 3 planting season per cycle.

CONCLUSION

The ultimate goal of plant breeding is the elimination of undesirable genes or accumulation of favorable genes into selected plants regardless of method used. Pedigree selection and population improvement methods presently available have been modified to fit the changing of breeding concepts. However, all methods available have entailed strong and weak points and gave inconsistent results due to different breeding materials, variation of environments, accuracy of collected data, experience of plant breeders, cultural practices and insensitivity of the method to identified high yield and high combining ability lines. However, population improvement can be used as a supplementary method of pedigree selection. The S_1 and testcross selections were designed for the selection of inbred performer *per se* and indirect combining ability of selected lines, respectively. In fact, both high yield and high combining ability lines were required for commercial hybrids. Therefore, alternate S_1 – diallel selections under nil – competition and competitive environments, respectively was proposed. The method should fulfill the requirement for the selection of both high yield and high combining ability inbreds. In addition,

Table 4 Yield and other selected traits of top-10 S5C0-single crosses tested at the National Corn and Sorghum Reseach Center.

Pedigree	Grain[1/] yield	Midparent	Heterosis	Moisture	Shelling	50% silking	Plant hight	Ear hight
	..........kg./ha...........		........................%........................			days	..............cm..........	
Ag210/Ag205	8,144 a-c	3826	112	35 a-g	77 f-m	54 b-d	189 c-h	107 d-f
Ag208/Ag204	7,847 a-d	3271	139	34 a-j	78 b-l	54 c-e	185 c-k	100 f-k
Ag210/Ag204	7,532 a-f	3643	106	33 d-m	76 f-m	53 c-f	184 c-m	100 f-k
Ag201/Ag208	7,500 a-f	4337	78	33 d-n	81 a-d	54 c-e	181 g-p	97 h-n
Ag207/Ag203	7,404 a-f	4253	74	36 a-d	82 a-c	53 d-g	194 a-f	110 b-e
Ag205/Ag208	7,199 b-h	3454	108	33 d-n	75 l-n	53 c-f	183 d-m	105 d-h
Ag209/Ag203	7,190 b-h	3504	105	32 g-p	79 b-h	52 e-g	188 c-h	110 b-e
Ag210/Ag203	7,150 b-h	4260	68	31 l-r	77 e-l	53 d-g	186 c-j	112 a-d
Ag206/Ag205	7,141 b-h	3474	105	33 d-n	74 n-k	53 c-f	203 a	120 a
Ag210/Ag202	7,141 b-h	3513	103	31 h-p	78 b-j	54 b-d	194 a-f	110 b-e
Check :								
Pioneer 3012	7,765 a-e	_	_	29 n-p	82 ab	55 a-c	203 a	110 b-e
CP989	6,479 f-m	_	_	30 m-p	78 b-l	56 ab	196 a-c	100 f-k
Syngenta NK45	8,469 a	_	_	29 p	79 b-g	55 a-c	195 a-d	94 j-o
Cargill 919	8,271 ab	_	_	31 k-p	83 a	54 b-d	172 l-t	92 k-o
%CV	8.84	_	_	5	2	1	3	5

[1/] Grain yield was measured at 15 % moisture.
– Means followed the same letter are not significant difference,

line selection should be done under nil-competition in the first few generations to allow full expression of genotypes.

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