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Effectiveness of Different Competition Environments and Thier Potential Use for the Development of Sweet Corn Inbreds and Hybrids (*Zea mays* L.)

Nguyen Tien Truong, Krisda Samphantharak* and Vatcharee Lertmongkol

ABSTRACT

Family selection was applied in segregated populations of three single crosses in three different environments; low-competition environment in non-replicated honeycomb design (HC), high plant density environment (HD) and alternate environments of the first two methods (HC-HD). Each family composed of 9 S_2 lines which was equally separated into 3 sets. Each set was applied into each selection environment and selfed to obtain 3 S_3HC, 3 S_3HD and 3 S_3 HC-HD for each family. Diallel cross was applied within each set and the best recovered single cross hybrid (A/A') of each set was testcrossed to corresponding lines within set to obtain 27 within set testcross hybrids (recovered three–way hybrids, A/A'//A''). Simultaneously, the 9 best recovered single cross hybrids were diallel crossed to form 36 sister line crosses, (A/A'//BB').

Selection for inbred line performance per se was effective in the respective manners; under low-competition environment in non-replicated honeycomb design, alternate environments and high plant density environment. High yield lines had a tendency to render high yield hybrids. However, ranking of yield could not be used as criterion for combining ability of lines. The sister line crosses either H × H or H × L were equally expressed in hybrid performances.

Key words: inbred, hybrid, corn, honeycomb selection

INTRODUCTION

The pure line method of maize (*Zea mays* L.) breeding has been the basic breeding method used in developing lines and hybrids since the suggestion of Shull in 1909. Modifications of pure-line method of breeding have been made during the past 80 years as information, techniques, and equipments become available (Hallauer, 1989). In addition, all breeding methods used the pedigree method for final improvement if the inbred lines are final goal (Troyer, 2001). However, the ultimate goal of sweet corn breeding is single cross of which needed high yield parental inbreds for economical return of commercial hybrid seed production. Low yield of most highly homozygous lines is the weak point of using highly inbreeding lines in commercial hybrid seed production. Several modified hybrids have been proposed to boost up yield of parental lines including sister line crosses, A/A'//B/B' (Jugenheimer, 1976) and recovered hybrid, A/A' (Tokatlidis *et al*., 2001).

Modification of plant spacing of which suitable for selection of line performance per se

Department of Agronomy, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand.
* Corresponding author, e-mail: agrkrs@ku.ac.th

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in mixed population (F_2, F_3...etc.) is still a controversial issue. Troyer and Rosenbrook (1983) proposed selection of corn inbreds under higher plant density than normal plant density, aiming to obtain inbreds of which could torelate to environmental stress. Subsequently, Troyer (1996) presented the supporting data of the successful commercial hybrids derived from inbreds selected under high plant density. However, Frey and Janick (1970) showed that plant under low-competition environment expressed maximal differentiation and hence facilitated visual selection. In addition, Fasoula (1990) found that selection for high yield lines in mixed population under high plant density resulted in low yield inbreds when planted in pure stands. On the contrary, the reverse result was obtained when lines were selected under low-competition environment. Besides, Tokatlidis *et al*. (2001) not only found that selection for inbred performance per se under low-competition environment was very effective but the derived single crosses (recovered hybrids) also gave higher yield than the original single cross when planted across different plant densities. The results also supported the finding of Frey and Janick (1970) that hybrids showed maximal differentiation under low density planting.

The present study therefore was aimed to find out the impact of line selection for performance per se under high, low and alternate plant densities. The potential use of different modified hybrids was also evaluated.

MATERIALS AND METHODS

S_1 seeds were derived from 3 single cross hybrids; $Agsh_2201/Agsh_2309$, $Agsh_2303/Agsh_2309$ and $Agsh_2201/Agsh_2318$, the 3 leading sweet corn hybrids of Department of Agronomy, Kasetsart University breeding program. They were planted in non-replicated honeycomb design. They were selfed and nine ears of S_2 were selected from each family and separated into 3 sets, each composed of 3 ears. Each set of each family was planted in each of 3 selection environments; firstly, high plant density (0.75 × 0.25 m), HD and designated as line number L_1 to L_9; secondly, low plant density (0.866 m) in non-replicated honeycomb design, HC as described by Fasoulas and Fasoula (1995) and designated as line number L_{19} to L_{27}; and thirdly, alternate environments between the first two environments and designated as line number L_{10} to L_{18}. Three plants within each 27 S_2 lines were selfed and mature seeds were bulked to maintain the number of lines.

Subsequently, seeds of each 27 S_3 lines were divided into two parts. The first part was subject to selection method as designed to obtained S_4 lines and the remnant seeds of the 9 S_3 sets from 3 families were diallel crossed within each set resulted in 27 intra-set hybrids (recovered single cross). The top intra-set hybrid of each set were diallel crossed to form 36 inter-set hybrids (sister line cross A/A'//B/B') and simultaneously, they were testcrossed to their corresponding 3 S_4 sister lines to obtain 27 intra-set testcross hybrids (recovered three-way hybrids; e.g. $A_1/A_2//A_1$, $A_1/A_2//A_2$, $A_1/A_2//A_3$...etc.).

The 36 inter-set diallel crosses and 27 intra-set testcross hybrids, 27 S_4 lines and 27 intra-set hybrids were tested for their yielding ability as well as some agronomic and quality traits required for commercial sweet corn hybrid. Trials were separately conducted in adjacent areas using randomized complete block design (RCBD) with 4 replications, 3 row plots of 5 m long and 0.75 × 0.25 m plant spacing, data were collected from the central rows. The three original single-cross hybrids, $Agsh_2201/Agsh_2309$, $Agsh_2303/Agsh_2309$ and $Agsh_2201/Agsh_2318$ plused 2 commercial sweet corn hybrids, Insee2 and Hybrix3 were included as common checks for all trials. Five plants in the border rows of each hybrid were selfed and harvested separately to evaluate quality traits.

All experiments were conducted from the

year 2003 to 2005 at National Corn and Sorghum Research Center, Suwan Farm (14°30’W, 101°30’ E, and 356 m asl.), in the Nakhon Ratchashima province, Thailand.

RESULTS AND DISCUSSION

Means and ranges of the 27 S_4 inbred lines from each set across three original sources are presented in Table 1. The overall mean grain yield ranged from 0.420 ton/ha of L_{23} to 1.104 tons/ha of L_{21} while grain yield of the four original inbred lines (checks) ranged from 0.532 ton/ha to 0.788 ton/ha. Four inbred lines gave significantly higher grain yield than the best inbred check, $Agsh_2201$; three of them were L_{21}, L_{24} and L_{25}, of which extracted under low-competition environment in non-replicated honeycomb design, each of them derived from $Agsh_2201/Agsh_2309$, $Agsh_2303/Agsh_2309$ and $Agsh_2201/Agsh_2318$, respectively. The other one, L_{17} was extracted under the alternate environments. In addition, grain yield of top inbred line from each family were from honeycomb selection under low-competition environment. Evidently, selection under low-competition environment was superior than selection under other two environments. The results were well agreed with the finding of Fasoula (1990) where true expression of genotypes occurred under low-competition environment. Considering the grand mean ($\overline{X}$) of each set; honeycomb selection under low-competition environment, alternate selection and high density selection were respectively effective methods of selection for inbred perfomance per se. Therefore, the lower competition between genotypes the higher selection efficiency would be obtained.

One of the limiting factors in the development of commercial single cross sweet corn hybrid is the seed yield of the female parent because it determines the cost of seed production. Therefore, it is necessary to select a high yielding and high combining ability female line or using recovered single crosses (A/A’) as parents. From a theoretical point of view, Marquez-Sanchez (1995) reported that the difference between the heterosis in the recovered hybrid and the heterosis in the original hybrid might indicate the type of gene action of the loci, which determined the character under improvement. Under partial dominance the recovered hybrid will yield more than the original hybrid, with complete dominance the two hybrids will yield the same, and with overdominance the recovered hybrid will yield less than the original hybrid. To address this goal, the top-9 intra-set or recovered single cross hybrids, one from each set presented in Table 2 were testcrossed to their corresponding S_4 line set to obtain intra-set testcross hybrids or recovered three-way crosses. In doing so, it was expected that each line retainsed some favorable genes of the other line at loci which they were lacking while additive effect of favourable loci was added due to crossing between closely related lines.

Green ear (ear with husk) yield and desirable traits for commercial sweet corn hybrid of the 27 intra-set testcross hybrids are presented in Table 3. The green ear yield of 27 intra-set testcross hybrids were significantly different. The top hybrid, $L_{25}/L_{27}//L_{27}$ was also significantly higher yield than $Agsh_2201/Agsh_2309$, $Agsh_2303/Agsh_2309$ and Insee2 hybrids, but statistically not higher than the original hybrid, $Agsh_2201/Agsh_2318$, and yielded equally to the best commercial hybrid, Hybrix3. However, Hybrix3 was significantly higher husked ear (ear without husk) yield than the best intra-set testcross hybrid but had lower recovery rate (w/w of grain/green ear). In contrast, the other commercial sweet corn hybrid, Insee2 had significantly lower green and husked ear yield and percentage of marketable ear but higher recovery rate than the best intra-set testcross hybrid. Considering mean of each set, the means of green and husked ear yield were highest where hybrids came from inbred lines selected under low-competition environment in

Table 1 Grain yields at 15 percent moisture of S_4 lines from 3 selection methods planted at Suwan Farm in January, 2005 (dry season).

	Inbred lines extracted from Agsh2-201/309			Inbred lines extracted from Agsh2-303/309			Inbred lines extracted from Agsh2-201/318			
	S_4 Line	Grain yield (tons/ha)	Shelling percentage	S_4 Line	Grain yield (tons/ha)	Shelling percentage	S_4 Line	Grai yield (tons/ha)		Shelling percentage
HD	S_4L_1	0.693^{e-g}	52.6^{b-i}	S_4L_4	0.815^{b-d}	60.0^{a-e}	S_4L_7	0.817^{b-d}		56.4^{a-i}
	S_4L_2	0.697^{e-g}	58.1^{a-h}	S_4L_5	0.543^{h-j}	48.7^{e-i}	S_4L_8	0.896^{b}		64.0^{a-c}
	S_4L_3	0.550^{h-j}	45.9^{h-i}	S_4L_6	0.425^{k}	49.5^{d-i}	S_4L_9	0.840^{bc}		59.3^{a-f}
	Average	***0.647***	***52.2***	**Average**	***0.594***	***52.7***	**Average**	***0.851***	$\bar{X}$ **= 0.697**	***59.9***
HC	S_4L_{19}	0.651^{f-i}	54.5^{a-i}	S_4L_{22}	0.852^{bc}	61.3^{a-d}	S_4L_{25}	1.024^{a}		51.9^{c-i}
	S_4L_{20}	0.548^{h-j}	57.8^{a-i}	S_4L_{23}	0.420^{k}	56.9^{a-i}	S_4L_{26}	0.868^{bc}		54.6^{a-i}
	S_4L_{21}	1.104^{a}	63.2^{a-c}	S_4L_{24}	1.072^{a}	66.4^{a}	S_4L_{27}	0.841^{bc}		55.8^{a-i}
	Average	***0.768***	***58.5***	**Average**	***0.781***	***61.5***	**Average**	***0.911***	$\bar{X}$ **= 0.820**	***54.1***
HC-HD	S_4L_{10}	0.658^{f-h}	64.7^{a-b}	S_4L_{13}	0.503^{jk}	46.4^{g-i}	S_4L_{16}	0.596^{g-j}		45.7^{i}
	S_4L_{11}	0.710^{d-g}	61.1^{a-d}	S_4L_{14}	0.686^{e-g}	55.8^{a-i}	S_4L_{17}	1.043^{a}		56.2^{a-i}
	S_4L_{12}	0.565^{h-j}	58.3^{a-g}	S_4L_{15}	0.895^{b}	54.9^{a-i}	S_4L_{18}	0.846^{bc}		59.5^{a-f}
	Average	***0.644***	***61.3***	***Average***	***0.695***	***52.4***	***Average***	***0.828***	$\bar{X}$ **= 0.722**	***53.8***

Check 1: $Agsh_2$-201 (check 1): 0.788^{b-e} with $61.7\%^{a-d}$ shelling percentage
Check 2: $Agsh_2$-303 (check 2): 0.626^{f-i} with $55.2\%^{a-i}$ shelling percentage
Check 3: $Agsh_2$-309 (check 3): 0.532^{i-k} with $61.1\%^{a-d}$ shelling percentage
Check 4: $Agsh_2$-318 (check 4): 0.746^{c-f} with $47.2\%^{f-i}$ shelling percentage

Table 2 Some important traits for commercial sweet corn hybrid of top intra-set hybrid (S_3 x S_3) of each set planted at Suwan Farm in January, 2005 (dry season).

Rank	Pedigree	Green ears yield	Husked ear yield	Marketable ears	Husked ear (w/w)	Recovery (%)	Ear length	Tip fill	Blank tip	Diameter	Kernel depth	Kernel row	Tenderness	Sweetness
		Tons/ha		%			cm						1-5	%
1	L_1/L_3	12.27^{c-g}	8.08^{d-f}	85.90^{a-f}	66.15^{a-e}	34.51^{c-i}	17.8	16.4	1.4	3.88	0.75	14.5	2.0	13.90
2	L_5/L_6	11.40^{d-j}	7.70^{ef}	87.15^{a-f}	68.55^{a-d}	43.51^{a-d}	16.9	14.3	2.5	;3.99	0.89	14.3	1.5	13.70
3	L_7/L_8	14.27^{bc}	9.63^{bc}	88.98^{a-e}	67.49^{a-d}	36.82^{a-i}	19.0	17.6	1.4	4.11	0.83	13.9	2.5	14.50
4	L_{10}/L_{12}	11.86^{c-h}	8.36^{d-f}	92.11^{a-d}	71.12^{a-b}	40.63^{a-f}	18.1	16.0	2.1	3.85	0.85	13.6	2.0	14.40
5	L_{13}/L_{15}	13.20^{c-e}	8.74^{c-e}	91.04^{a-d}	66.96^{a-d}	38.86^{a-h}	17.5	13.7	3.7	4.42	0.97	15.1	2.0	14.90
6	L_{16}/L_{18}	13.20^{c-e}	7.37^{f}	75.22^{e-h}	56.35^{b-e}	29.24^{e-i}	19.2	17.4	1.8	3.91	0.78	14.1	2.0	13.95
7	L_{19}/L_{20}	13.02^{c-f}	9.27^{b-d}	90.90^{a-d}	72.03^{a}	39.64^{a-g}	19.2	17.0	2.2	4.06	0.84	15.1	2.0	15.15
8	L_{22}/L_{24}	11.48^{d-i}	8.28^{d-f}	98.81^{a}	72.52^{a}	48.37^{a}	19.0	16.3	2.7	3.98	0.90	13.7	2.0	14.40
9	L_{25}/L_{27}	17.07^{a}	10.09^{b}	87.08^{a-f}	59.41^{a-e}	31.66^{d-i}	20.0	17.7	2.3	4.24	0.85	13.9	2.0	14.85
Check1	$Agsh_2$-201/309	16.13^{ab}	11.39^{a}	95.00^{a-b}	70.11^{a-c}	39.89^{a-g}	20.3	18.0	2.3	4.27	0.92	15.1	2.0	14.10
Check2	$Agsh_2$-303/309	16.20^{ab}	11.49^{a}	97.50^{a-b}	70.43^{a-b}	43.48^{a-d}	18.7	16.9	1.8	4.01	0.93	14.5	1.5	13.97
Check3	$Agsh_2$-201/318	13.07^{c-e}	9.25^{b-d}	96.30^{a-b}	70.8^{a-b}	37.74^{a-i}	18.4	16.3	2.1	4.10	0.86	14.4	2.5	14.63
Mean		13.11	8.44	86.48	66.00	37.45	18.1	15.9	2.2	4.00	0.85	14.2		14.36
CV(%)		11.93	6.76	9.57	13.25	18.86	5.6	7.9	24.7	4.37	9.12	4.0		3.36

Table 3 Green and husked ear yield, percentage of husked ears, marketable yield and recovery of Intra-set testcross hybrids planted at Suwan Farm, Thailand, July 2005 (rainy season).

	Parent were extracted from Agsh2-201/309						Parent were extracted from Agsh2-303/309						Parent were extracted from Agsh2-201/318					
	Hybrid	Green ear yield (tons/ha)	Husked ear yield (tons/ha)	Marke_ table Ears	Husked ear (w/w)	Recovery	Hybrid	Green ear yield (tons/ha)	Husked ear yield (tons/ha)	Marketable ears	Husked ear (w/w)	Recovery	Hybrid	Green ear yield (tons/ha)	Husked ear yield (tons/ha)	Marketable ears	Husked ear (w/w)	Recovery
					%.						%						%	
HD	$L_1/L_3//L_1$	10.20^{e-j}	4.53^{k-m}	57.83^{e-f}	44.49^{f-g}	21.74^{f-g}	$L_5/L_6//L_4$	9.40^{g-j}	4.17^{l-m}	61.26^{d-f}	44.30^{f-g}	26.84^{c-g}	$L_7/L_8//L_7$	11.60^{c-h}	5.97^{d-k}	75.18^{a-d}	51.99^{b-g}	25.13^{d-g}
	$L_1/L_3//L_2$	10.07^{e-j}	5.00^{h-m}	65.56^{b-f}	50.13^{c-g}	27.48^{b-g}	$L_5/L_6//L_5$	9.93^{f-j}	4.67^{k-m}	60.44^{d-f}	47.02^{d-g}	25.35^{d-g}	$L_7/L_8//L_8$	13.60^{a-d}	6.97^{b-f}	75.53^{a-d}	50.99^{b-g}	31.03^{b-e}
	$L_1/L_3//L_3$	8.93^{h-j}	4.70^{k-m}	67.15^{a-f}	52.93^{a-g}	25.24^{d-g}	$L_5/L_6//L_6$	11.13^{c-i}	5.77^{e-k}	67.14^{a-f}	52.23^{b-g}	31.05^{b-e}	$L_7/L_8//L_9$	12.87^{a-e}	7.13^{b-e}	76.44^{a-d}	55.54^{a-d}	32.00^{b-e}
	Average	***9.73***	***4.74***	***63.51***	***49.18***	***24.82***	**Average**	***10.15***	***4.87***	***62.95***	***47.85***	***27.75***	**Average**	***12.69***	***6.69***	***75.72***	***52.84***	***29.39***
HC	$L_{19}/L_{20}//L_{19}$	11.93^{c-g}	6.33^{b-j}	69.78^{a-f}	52.54^{a-g}	25.09^{d-g}	$L_{22}/L_{24}//L_{22}$	11.47^{c-h}	6.53^{b-h}	67.53^{a-f}	50.01^{c-g}	33.44^{b-d}	$L_{25}/L_{27}//L_{25}$	13.33^{a-d}	7.20^{b-e}	71.52^{a-f}	46.26^{e-g}	25.35^{d-g}
	$L_{19}/L_{20}//L_{20}$	11.73^{c-h}	6.40^{b-i}	65.13^{b-f}	48.78^{c-g}	25.60^{d-g}	$L_{22}/L_{24}//L_{23}$	11.87^{c-g}	5.87^{d-k}	57.97^{e-f}	46.31^{e-g}	30.30^{b-f}	$L_{25}/L_{27}//L_{26}$	12.87^{a-e}	6.67^{b-g}	61.73^{c-f}	52.25^{b-g}	28.03^{b-g}
	$L_{19}/L_{20}//L_{21}$	11.53^{c-h}	5.87^{d-k}	57.81^{e-f}	48.60^{c-g}	27.92^{b-g}	$L_{22}/L_{24}//L_{24}$	10.93^{d-i}	6.00^{c-k}	64.23^{b-f}	54.02^{a-e}	33.38^{b-d}	$L_{25}/L_{27}//L_{27}$	15.07^{a-b}	7.57^{b-c}	79.60^{a-b}	49.47^{c-g}	25.46^{d-g}
	Average	***11.73***	***6.20***	***64.24***	***49.97***	***26.20***	**Average**	***11.42***	***6.13***	***63.24***	***50.11***	***32.37***	**Average**	***13.76***	***7.15***	***70.95***	***49.33***	***26.28***
Alter	$L_{10}/L_{12}//L_{10}$	10.87^{d-j}	4.87^{i-m}	61.67^{c-f}	45.55^{e-g}	23.79^{e-g}	$L_{13}/L_{15}//L_{13}$	12.13^{c-g}	7.10^{b-e}	75.16^{a-d}	56.10^{a-d}	35.21^{b-c}	$L_{16}/L_{18}//L_{16}$	12.40^{b-f}	6.07^{c-k}	65.68^{b-f}	49.44^{c-g}	26.27^{d-g}
	$L_{10}/L_{12}//L_{11}$	8.47^{i-j}	3.67^{m}	55.51^{f}	43.82^{g}	21.23^{g}	$L_{13}/L_{15}//L_{14}$	10.13^{e-j}	4.80^{j-m}	68.68^{a-f}	45.71^{e-g}	25.61^{d-g}	$L_{16}/L_{18}//L_{17}$	11.07^{c-i}	5.43^{f-l}	75.94^{a-d}	49.13^{c-g}	23.23^{e-g}
	$L_{10}/L_{12}//L_{12}$	8.20^{j}	4.20^{l-m}	61.12^{d-f}	51.32^{b-g}	29.30^{b-g}	$L_{13}/L_{15}//L_{15}$	11.47^{c-h}	6.47^{b-h}	72.78^{a-e}	49.85^{c-g}	32.04^{b-e}	$L_{16}/L_{18}//L_{18}$	13.80^{a-c}	7.77^{b}	73.35^{a-e}	56.44^{a-c}	30.52^{b-f}
	Average	***9.18***	***4.25***	***59.43***	***46.90***	***24.77***	***Average***	***11.24***	***6.12***	***72.21***	***50.55***	***30.95***	***Average***	***12.42***	***6.42***	***71.66***	***51.67***	***26.67***
Origin hybrids	$Agsh_2$-201/309	11.87^{c-g}	7.25^{b-e}	77.72^{a-c}	61.15^{a}	43.19^{a}	$Agsh_2$-303/309	11.47^{c-h}	6.05^{c-k}	69.20^{a-f}	53.50^{a-f}	26.74^{c-g}	$Agsh_2$-201/318	12.90^{a-e}	7.37^{b-d}	76.01^{a-d}	56.83^{a-c}	32.84^{b-d}
Check	$Hybrid_3$	15.47^{a}	9.30^{a}	81.89^{a}	59.90^{a-b}	23.35^{e-g}		$Insee_2$	11.80^{c-g}	5.37^{g-l}	65.84^{a-f}	45.58^{e-g}	35.79^{b}					

honeycomb design, regardless of original germplasms. However, the other traits such as percentage of marketable ear, husked ear yield and recovery rate of hybrids were not statistically different, regardless of selection methods across original germplasms.

The top green ear yield of three way recovered hybrids from each of 9 sets, 8 were from backcrossing to one of the parental lines and the remaining one ranked second within set. Obviously, strong additive effect played an important role in the expression of green ear yield heterosis of three way recovered hybrids. Besides, the top husked ear yield of three way recovered hybrids of each set, 7 out of 9 sets were from backcrossing to one of their parents.

Moreover, some recovered backcross hybrids ($L_{16}/L_{18}//L_{18}$, $L_{25}/L_{27}//L_{27}$, $L_{13}/L_{15}//L_{13}$, and $L_{22}/L_{24}//L_{22}$) showed higher husked ear yield but not statistically significant than the corresponding hybrids. This implied a strong additive effect for the expression of husked ear yield heterosis. Similar results in field corn were reported by Tokatlidis *et al*. (2001).

Because all S_4 lines were weakened and susceptible to leaf diseases, in order to boost up parent yield, top recovered single cross hybrids, one from each set as presented in Table 2 were used as parents to form sister line crosses. However, for simplicity, the recovered single cross hybrids (A/A') and sister line crosses (A/A'//B/B') would be referred to as F_1 lines and double crosses, respectively.

Green and husked ear yield and desirable traits required for commercial sweet corn of top-10 double cross hybrids are presented in Table 4. The top double cross hybrids showed similar green ear yield to the best commercial check hybrid, Hybrix3, but somewhat higher yield than Insee2 even though it was not statistically significant. However, other 9 hybrids gave higher green ear yield than 4 out of 5 checks although not statistically different. On the other hand, the top-10 double cross hybrids gave equally husked ear yield to the best check hybrid, Hybrix3. The best two double cross hybrids for both green and husked ear yield, $L_{13}/L_{15}//L_{16}/L_{18}$ and $L_{10}/L_{12}//L_{16}/L_{18}$ were involved with F_1 lines derived from lines selected under alternate environments. Line L_{16}/L_{18} and L_{13}/L_{15} ranked 1st and 2nd respectively for combining ability among the 9 selected lines (Table 4). The L_{22}/L_{24} derived from 2 high yielding lines (Table 1) but it ranked the 5th for combining ability among 9 selected F_1 lines. Considering yield of F_1 lines (Table 2), L_1/L_3, L_7/L_8, L_{13}/L_{15}, L_{16}/L_{18}, L_{14}/L_{20}, and L_{25}/L_{27}, they were considered as high yield lines while L_5/L_6, L_{10}/L_{12} and L_{22}/L_{24} were relatively low yield lines. The high yield line L_1/L_3 failed to produce the top-10 double cross hybrids. Four of the top-10 double cross hybrids were from H x H and the remaining 6 double cross hybrids came from H × L. However, L_{16}/L_{18}, L_{13}/L_{15} and L_{25}/L_{27} ranked the 1st, 2nd and 3rd for general combining ability for both green and husked ear yield involved in 9 out of top-10 double cross hybrids. The top-3 double cross hybrids came from H × H while L_{22}/L_{24} ranked the 5th for general combining ability and low yield involved in 4 out of top-10 double cross hybrids. Therefore, genneral combining ability as well as specific combining ability played roles in the expression of heterosis of inter-family hybrids. The results implied the finding of Lamkey and Hallauer (1986) that selection for high and low yield lines effectively separated lines into high and low combining ability groups but yield of lines within group could not be used as criterion for combining ability of lines. Since all S_4 lines in present study were selected by performance per se, they should be considered as high yield group. Most of top-10 double crosses involved with S_4 lines either selected from low plant density or alternated selection and only 3 crosses had 1 of their parents from high plant density selection. This implied the effectiveness of selection under low and alternate environments, in order to obtain high yield and high combining lines.

Table 4 Green ear and husked ear yields and some important traits for sweet corn hybrid of top ten double modified single cross hybrids or sister line cross planted at Suwan Farm in July, 2005 (rainy season)

Rank order	Pedigree	Green ear yield	Husked ear yield	% marketable ears	% husked ear (w/w)	Recovery (%)	Parent lines	Green ear yield (tons/ha)	General Combining ability
		Tons/ha							
1	$L_{13}/L_{15}//L_{16}/L_{18}$	16.27^{a-b}	10.30^{a-b}	88.83^{a-d}	63.66^{b-f}	41.32^{a-g}	L_1/L_3	12.27^{c-g}	- 1.41
2	$L_{10}/L_{12}//L_{16}/L_{18}$	15.00^{a-c}	10.43^{a}	88.65^{a-d}	69.55^{a-c}	42.97^{a-d}	L_5/L_6	11.40^{d-j}	- 0.46
3	$L_{13}/L_{15}//L_{25}/L_{27}$	14.53^{a-d}	9.23^{a-f}	87.79^{a-d}	63.74^{b-f}	32.94^{i-j}	L_7/L_8	14.27^{bc}	0.08
4	$L_{22}/L_{24}//L_{25}/L_{27}$	14.33^{a-e}	9.70^{a-e}	87.95^{a-d}	67.94^{a-d}	42.36^{a-e}	L_{10}/L_{12}	11.86^{c-h}	- 0.48
5	$L_7/L_8//L_{22}/L_{24}$	14.27^{a-e}	9.57^{a-e}	88.58^{a-d}	67.03^{a-d}	44.42^{a-b}	L_{13}/L_{15}	13.20^{c-e}	1.03
6	$L_{16}/L_{18}//L_{22}/L_{24}$	14.27^{a-e}	10.27^{a-b}	93.65^{a}	71.74^{a}	45.67^{a}	L_{16}/L_{18}	13.20^{c-e}	1.26
7	$L_7/L_8//L_{13}/L_{15}$	14.13^{a-f}	9.70^{a-e}	90.35^{a-c}	68.27^{a-d}	43.21^{a-d}	L_{19}/L_{20}	13.02^{c-f}	- 0.75
8	$L_5/L_6//L_{16}/L_{18}$	14.00^{b-g}	9.97^{a-c}	90.43^{a-c}	71.09^{a-b}	43.75^{a-c}	L_{22}/L_{24}	11.48^{d-i}	- 0.01
9	$L_{13}/L_{15}//L_{22}/L_{24}$	13.87^{b-h}	9.07^{a-g}	85.69^{a-d}	65.35^{a-f}	42.72^{a-e}	L_{25}/L_{27}	17.07^{a}	0.74
10	$L_{16}/L_{18}//L_{19}/L_{20}$	13.87^{b-h}	9.77^{a-d}	93.62^{a}	70.64^{a-b}	40.26^{a-i}			
Check1	12.27^{c-l}	8.68^{a-h}	86.01^{a-d}	70.63^{a-b}	43.45^{a-d}				
Check2	12.83^{c-k}	8.32^{a-i}	77.10^{c-g}	64.93^{a-f}	41.51^{a-g}				
Check3	12.00^{c-l}	8.12^{c-j}	86.14^{a-d}	67.55^{a-d}	41.17^{a-g}				
Insee2	13.47^{b-h}	7.80^{d-k}	80.90^{a-f}	57.82^{f-g}	31.50^{j}				
Hybrid3	16.87^{a}	10.43^{a}	79.85^{a-g}	61.78^{d-g}	34.83^{f-j}				
Mean	14.45	8.24	83.32	64.90	39.20				
CV(%)	13.60	15.10	9.55	6.73	10.74				

Marketable ear percentage of the top double cross hybrid was 93.65 and not statistically different from 80.90 and 79.85 percents of the commercial sweet corn hybrids, Insee2 and Hybrix3, respectively. However, 5 double cross hybrids gave significantly higher percentage of husked ear yield than the best commercial sweet corn check, Hybrix3. Moreover, two commercial hybrids, Hybrix3 and Insee2 also had significantly lower recovery percentage than the top 9 double cross hybrids. These results might be due to the lower husked ear yield and recovery percentages of Hybrix3 and Insee2 than the original hybrids, $Agsh_2201/Agsh_2309$, $Agsh_2303/Agsh_2309$ and $Agsh_2201/Agsh_2318$.

In general, most of agronomic and quality traits for commercial sweet corn hybrid of double cross hybrids were similar to the commercial checks and the original hybrids. This was because of all breeding germplasms used in this study were leading hybrids selected for high quality.

CONCLUSION

Selection for inbred performance per se under low competition environment was a very effective method for improving potential yield of inbreds and the derived hybrids. The additive effect of intra-locus played a major role for heterosis expression in recovered hybrids while additive effects of intra-locus and inter-loci were equally important in the expression of heterosis of inter family hybrids. Ranking of yield within high yielding group did not imply the ranking of combining ability of lines. While selection under low competion environment was superior in identifying high yield lines, alternate selection as well as selection under low competition environment were somewhat equally effective to identify lines for good inter-family hybrids. However, line selection under low competition environment were a useful method for the improvement of original parent lines and retained yielding ability of recovered hybrid. Sister line crosses should be an alternative method where weakness of inbred lines become problem in commercial single cross seed production of sweet corn.

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