RESEARCH ARTICLE

SABRAO Journal
of Breeding and Genetics
45 (3) 468-477, 2013

COMBINING ABILITY OF SUPER SWEET CORN INBRED LINES WITH DIFFERENT EAR SIZES FOR EAR NUMBER AND WHOLE EAR WEIGHT

J. WORRAJINDA[1], K. LERTRAT[1,2*] and B. SURIHARN[1,2]

[1]Department of Plant Science and Agricultural Resources, Faculty of Agriculture,
Khon Kaen University, Khon Kaen, Thailand 40002
[2]Plant Breeding Research Center for Sustainable Agriculture,
Khon Kaen University, Khon Kaen, Thailand 40002
*Corresponding author's email: kamol9@gmail.com

SUMMARY

The information on general combining ability (GCA) and specific combining ability (SCA) is important for hybrid development. The objective of this study was to determine GCA and SCA effects for number of ear and whole ear weight of eight sweet corn inbred lines. Four inbred lines with small ears (S) extracted from KKU-WTMsh population and four inbred lines with large ears (L) extracted from KKU-WSHCsh populations were crossed in a diallel fashion to produce 56 F_1 hybrids. The hybrids and the inbred lines were evaluated in a randomized complete block design with three replications in the rainy season 2011 and the dry season 2011/12. Data were recorded for number of ear and whole ear weight at green harvest. GCA, SCA and reciprocal effects were significant for ear number and whole ear weight. GCA variance was more important for number of ear than SCA variance indicating that predominance of additive gene action but SCA variance was higher for ear weight. MS37 had positive and high GCA effect for number of ear, whereas DKA was a good combiner for whole ear weight. MS59×MS136 and MS59×MS88 had the highest ear number in the rainy season, whereas MS37×MS88 was the best genotype for this trait in the dry season. DKA×MS37 performed best for whole ear weight in the rainy season, while DKA×MS88 was performed best in the dry season. The hybrids between large ear inbreds and small ear inbreds had average whole ear weights of 16,581 and 17,294 kg ha^{-1} in the rainy and dry seasons, respectively, and average whole ear weights of the crosses between the inbreds with small ears and the inbreds with large ears were higher than those of the hybrids within the inbreds with large ears. The hybrids between the inbreds with large ears and the inbreds with small ears were more prolific than the hybrids of the inbreds within the large ear group. Therefore, the development of new single cross hybrids in order to increase number of ear per plant could be achieved through the cross breeding between the population with different ear sizes.

Keywords: *Zea mays* L. *saccharata*, breeding, diallel, hybrid variety

Manuscript received: November 18, 2012; Decision on manuscript: August 4, 2018; Manuscript accepted: September 17, 2013.

Communicating Editor: Bertrand Collard

INTRODUCTION

Sweet corn is an important vegetable crop worldwide. It is a rich source of tocopherols, carotenoids, vitamin C and phenolics (Dewanto *et al.,* 2002; Ibrahim and Juvik, 2009).Unlike normal corn, sweet corn (*Zea mays* L.) has been intensively improved for quality and appearance, but little effort has made to improve yield (Cartea *et al.,* 1996). Quality traits such as flavor, tenderness, sweetness, creamy texture, appearance, aroma and low starch content are most important in sweet corn breeding programs (Carey *et al.,* 1984; Lertrat and Pulam, 2007). However, high yield is still a primary goal of most plant breeding programs including sweet corn (Ferh, 1987). In addition to, kernel quality and agronomic characters such as ear size, ear shape, kernel color, size unique to specific market are also important characters in sweet corn (Lertrat and Pulam, 2007). Bulk evidence has indicated that increased ears per plant or prolificacy are associated with grain yield in maize (Uhr and Goodman, 1995; Maita and Coors, 1996; Jampatong *et al.,* 2000) and small-ear waxy corn (Kesornkeaw *et al.,* 2009). However, a study in sweet corn also showed negative association between prolificacy and percentage of usable ears (Younes and Andrew, 1978). The contrasting results in the previous studies lead us to hypothesize whether it is possible to improve prolificacy and yield in sweet corn hybrids through the crosses between inbred lines with differences in ear size.

Parental inbreds with good general combining ability (GCA) are necessary for hybrid development, and the hybrids with good specific combining ability (SCA) for ergonomically important traits are also important. Combing ability study is, therefore, a crucial step in hybrid breeding programs, and it is used for evaluation of sweet corn for yield, quality (Solomon *et al.,* 2012), prolificacy (Younes and Andrew, 1978), flowering time and agronomic characters (Dickert and Tracy, 2002) and in grain maize for grain yield and some growth characters (Rana and Kapoor 2003; Ünay *et al.,* 2004; Subramanian and Subbaraman, 2006; Uddin *et al.,* 2006), protein and tryptophan contents (Machida *et al.,* 2010), drought tolerance (Durães *et al.,* 2002), cool tolerance (Rodríguez *et al.,* 2007) downy mildew resistance (Kim *et al.,* 2003) and corn earworm resistance (Matthews *et al.,* 2007).

However, the information on combing ability for prolificacy of parental lines of sweet corn with different ear sizes is still lacking. A better understanding on combining ability of sweet corn inbreds with different ear sizes will assist in sweet corn breeding programs. Therefore, the objective of this study was to determine GCA and SCA effects for number of ear and whole ear weight of eight sweet corn inbred lines.

MATERIALS AND METHODS

Plant material

Four corn inbred lines with big ear size (DKA, DKB1, DKB2 and DKC) and four corn inbred lines with small ear size (MS37, MS59, MS88 and MS136) were used as the parents in this study. The former group of inbred lines was developed from KKU-WSHCsh population that represents big ear and high yield improved population, and the latter group of inbred lines was developed from KKU-WTMsh population that represents good eating quality, small ear and double ear population. These two populations were self-pollinated from S_0 to S_4 generations. The resulting S_4 inbred lines were crossed to obtain all possible crosses with reciprocal crosses during 2010 in Khon Kaen, Thailand.

Field experiment

The 28 hybrids, 28 reciprocals and the eight parental lines were evaluated in a randomized complete block design with three replications in the rainy season 2011 and dry season 2011/12 at Experimental Farm of Khon Kaen University, Thailand (16^{o}47′ N, 102^{o}81′ E, 200 msl).

The plot size was two-row plot with five-meters in length and spacing of 80 x 25 cm. Conventional tillage was practiced for soil preparation, and 15-15-15 fertilizer of N-P-K as basal dose at the rate of 171 kg ha^{-1} was incorporated into the soil during soil preparation. Two splits of 15-15-15 fertilizer at the rate of 93.75 kg ha^{-1} plus urea (46-0-0) at the rate of 93.75 kg ha^{-1} for first split and 15-15-15 fertilizer at the rate of 125 kg ha^{-1} plus urea at the rate of 62.5 kg ha^{-1} for second split were applied to the crop at 14 days after planting (DAP) and 30 DAP, respectively. At flowering stage, 13-13-21 fertilizer was applied at the rate of 156.25 kg ha^{-1}. Therefore, there were a total dose of fertilizers of 150.65 kg ha^{-1} nitrogen, 78.78 kg ha^{-1} phosphorus and 91.27 kg ha^{-1} potassium, respectively. Irrigations were supplied frequently to avoid drought stress. Insect pests, diseases and weed were appropriately managed to obtain optimum growth and yield of the crop for both the rainy and the dry seasons.

Data collection

Data from each plot were recorded for number of ears (ear ha^{-1}) and whole ear weight (kg ha^{-1}). As low temperature delayed maturity, harvest time was determined as 18 days after silking in the rainy season and 21 days after silking in the dry season. At harvest, total number of ears were weighted, and whole weight ears on per harvest area of 7.5 m^2 (2 rows, 40 plants) was converted to per hectare.

Data analysis

Analysis of variance was performed for each character, and a combined two-factor analysis of variance was conducted after variance homogeneity was tested (Gomez and Gomez, 1984). Combined analysis of variance was not performed although variances for all characters under investigation were homogeneous, and data of two seasons were reported separately. Duncan's new multiple range test (DMRT) was used to compare means. Orthogonal comparison was also used to compare the differences among four groups of hybrid including S x S group (12 hybrids), S x L group (16 hybrids), L x S ears group (16 hybrids) and L x L ears group (12 hybrids).

Diallel analysis of combining ability was carried out using Method 1, Model I of Griffing (1956). Test of significant difference from zero for GCA and SCA effects was performed using t-test.

RESULTS

Mean squares for ear number and whole ear weight are showed in Table 1. Differences between seasons (S) were highly significant ($P \leq 0.01$) for whole ear weight, and significant difference ($P \leq 0.05$) between seasons was also observed for number of ears. Highly significant differences ($P \leq 0.01$) among corn genotypes (G) were found for ear number and whole ear weight. The interactions between season and genotype (G × S) were also highly significant ($P \leq 0.01$) for these traits.

The effects of general combining ability (GCA), specific combining ability (SCA) and reciprocal were highly significant ($P \leq 0.01$) for ear number and whole ear weight in both seasons (Table 2). Highly significant effects ($P \leq 0.01$) of reciprocal were observed for ear number and whole ear weight in both seasons.

The contributions of GCA effects and SCA effects to total variations in general were high, ranging from 43.7 to 64.3% in the rainy season and 34.3 to 71.2% in the dry season for GCA and from 17.4 to 40.7% in the rainy season and 7.6 to 45.3% in the dry season for SCA. Reciprocal effects, though significant, shared small portion of total variations, ranging from 5.5 to 6.8% in the rainy season 2011 and 8.0 to 8.4% in the dry season 2011/12.

GCA effects were consistently higher than SCA effects for ear number. The contributions of GCA effects and SCA effects, though high, were not consistent between seasons for whole ear weight.

Sweet corn grown in the dry season had higher ear number (81,041 ears ha^{-1}) and whole ear weight (13,506 kg ha^{-1}) than did the crop grown in the rainy season (67, 986 ears ha^{-1} and 9,338 kg ha^{-1}) (Table 3). Highly significant differences ($P \leq 0.01$) among the inbred lines were observed for ear number and whole ear weight in the rainy season and the dry season. MS37 had the highest ear number in both rainy and dry seasons (105,500 ears ha^{-1} and 110,650 ears ha^{-1}), but it also had low whole ear weight in both seasons. Similar to MS88, MS136 and MS59 were also high for ear number in both seasons, but they were also low for whole ear weight. DKA was consistently high for whole ear weight. DKB1, DKB2 and DKC were rather high for whole ear weight, but their performance was more variable between seasons than DKA.

Positive and high GCA effects are desirable for ear number and whole ear weight. By using these criteria for selection, MS37 was the best parent with the highest GCA effects for ear number in both seasons (Table 4). DKA showed positive, high and consistent GCA effects for whole ear weight, whereas DKB2 and

DKC showed high and positive GCA effects for whole ear weight and in the rainy season only.

Table 5 showed specific combining ability for ear number of the crosses among sweet corn inbred lines with small ear size (upper, left hand quadrant), the crosses among sweet corn inbred lines with large ear size (lower, right hand quadrant), the direct crosses between different groups using the inbred lines with small ear size as female parents (upper, right hand quadrant) and the reciprocals (lower, right hand quadrant). The overall mean is also provided for each season for mean comparison. High and positive SCA is preferable for ear number. In the rainy season (Table 5a), Direct crosses and reciprocals of different groups had high number of crosses with significant and positive SCA effects (6 for direct cross and five for reciprocal), whereas the crosses in the same group gave low number of crosses that showed high and positive SCA effects (four for big ear group and two for small ear group).

The similar pattern was observed in the dry season. Eight crosses showed high and significant SCA effects for the direct crosses between different group, and eight crosses showed high and significant SCA effects. In contrast, six crosses showed high and significant SCA effects in the crosses among small ear group, and only three crosses showed significant and positive SCA effects in the crosses among large ear group.

The genotypes with the highest SCA effects for ear number in each season were those in the crosses between the different groups. MS59×DKB1 had the highest SCA effect for ear number (1,725 ears ha^{-1}) in the rainy season. However, the crosses among the same groups also had high SCA effects for ear number. These included DKC×DKB2 (11,738 ears ha^{-1}) and MS59×MS136 (14,488 ears ha^{-1}).In the dry season, the genotypes with the highest SCA effects were MS88×DKB2 (6,019 ears ha^{-1}), MS136×DKC (5,688 ears ha^{-1}) and MS88×DKB1 (5,600 ears ha^{-1}).

Table 6 showed specific combining ability (SCA) for whole ear weight. The highest numbers of crosses showing high and significant SCA effects were observed among the crosses of inbred lines with large ears as male parents and the inbred lines with small ear as female parents (12 crosses in the rainy season and 16 crosses in the dry season). The reciprocal crosses of inbred lines with difference in ear sizes also had high numbers of crosses that showed high and significant SCA effects for whole ear weight (eight crosses in the rainy season and seven crosses in the dry season).

The crosses between inbred lines in the same groups had low numbers of crosses with high and significant SCA effects for whole ear weight. For the crosses within large ear group, there were three crosses in the rainy season and three crosses in the dry season. For the crosses within small ear group, there were three crosses in the rainy season and two crosses in the dry season.

The crosses with positive and significant SCA effects for whole ear weight are preferable, and, thus, the best crosses for each season were readily identified. MS37×DKA and MS37×DKB1 were the best genotypes with highest SCA effects for whole ear weight (3,950 kg ha^{-1} and 3,650 kg ha^{-1}, respectively) in the rainy season, and these genotypes also had high and positive SCA effects in the dry season (1,269 kg ha^{-1} and 3,744 kg ha^{-1}, respectively). However, the best genotypes in the dry season were MS88×DEKB1 (4,488 kg ha^{-1}), MS88×DKB2 (3,906 kg ha^{-1}) and MS136×DKA (3,825 kg ha^{-1}). Moreover, MS37×DKB1 was the highest hybrid for whole ear weight across seasons (data not showed).

Orthogonal comparison among groups of corn hybrids indicated that the crosses among inbreds with small ears had the highest ear number in the rainy season and the dry season (Table 7). The crosses among inbreds with large ears also had the highest whole ears weight especially in the rainy season. However, the crosses among inbreds with large ears and inbreds with small ears had the highest whole ear weight in the dry season. The correlation coefficient between ear number and whole ear weight was positive and significant (r = 0.11, $P \leq 0.01$) (data not reported).

Table 1. Mean squares for number of ear and whole ear weight of 64 corn genotypes evaluated for two seasons in the rainy season 2011 and dry season 2011/12.

Source of variation	df	Number of ears	whole ear weight
Season (S)	1	84,604,242*	118,007,906**
Rep. within S	4	4,643,482	1,716,229
Genotype (G)	63	23,923,953**	2,872,293**
GxS	63	3,630,289**	385,299**
Error	252	1,135,451	120,313
C.V. %		8.73	12.03

*, ** significant at 0.05 and 0.01 probability levels, respectively

Table 2. Mean squares and % sum of mean squares (in parenthesis) for combining ability of ear and whole ear weight of 64 corn genotypes in the rainy season 2011 and in the dry season 2011/12.

Source of variation	df	Rainy season		Dry season	
		Ear number	Whole ear	Ear number	whole ear
GCA	7	28,989,354** (64.3)	1,622,145** (43.7)	35,069,449** (71.2)	2,507,833** (34.3)
SCA	28	1,961,281** (17.4)	377,775** (40.7)	937,220** (7.6)	827,479** (45.3)
Reciprocal	28	766,100** (6.8)	51,066** (5.5)	988,130** (8.0)	154,326** (8.4)
Error	105	346,257 (11.5)	24,761 (10.0)	433,175 (13.2)	58,087 (11.9)

** significant and highly significant at 0.01 probability level

Table 3. Means for number of ear and whole ear weight of 8 parental lines in the rainy season 2011 and dry season 2011/12.

Inbred	Rainy season		Dry season	
	Ear number (ears ha^{-1})*	Whole ear weight (kg ha^{-1})	Ear number (ears ha^{-1})	Whole ear weight (kg ha^{-1})
DKA	$55,519^{u-x}$	$15,600^{e-q}$	$79,575^{h-o}$	$21,100^{i-r}$
DKB1	$66,644^{l-w}$	$11,075^{u-x}$	$65,794^{o-x}$	$19,313^{o-u}$
DKB2	$54,444^{w-x}$	$14,375^{j-u}$	$50,000^{y}$	$15,831^{s-w}$
DKC	$56,088^{u-x}$	$12,413^{q-x}$	$64,775^{p-x}$	$14,469^{u-x}$
MS59	$64,594^{o-w}$	$5,406^{y}$	$86,906^{d-l}$	$9,081^{yz}$
MS136	$67,225^{l-w}$	$4,850^{y}$	$93,750^{c-h}$	$9,775^{x-z}$
MS37	$105,500^{a}$	$6,281^{y}$	$110,650^{a}$	$10,206^{x-z}$
MS88	$73,875^{h-q}$	$4,700^{y}$	$96,875^{b-e}$	$8,275^{z}$
Mean	67,986	9,338	81,041	13,506

*Means in the same column with the same letter (s) are not statistically different at 0.05 probability level by DMRT.

Table 4. General combining ability (GCA) for number of ear and whole ear weight of eight parental lines in the rainy season 2011 and dry season 2011/12.

Inbred	Rainy season		Dry season	
	Ear number (ears ha^{-1})	Whole ear weight (kg ha^{-1})	Ear number (ears ha^{-1})	Whole ear weight (kg ha^{-1})
DKA	-6,388	2,425*	-4,525	3,075**
DKB1	-3,144	763	-5,794	2,656*
DKB2	-11,081**	1,813*	-14,769**	956
DKC	-5,900	1,750*	-5,150	1,469
MS59	2,106	-2,613*	2,531	-3,888**
MS136	2,369	-1,388	5,275	-2,006
MS37	15,156**	-281	13,944**	-238
MS88	6,881	-2,469**	8,488*	-2,019

*, ** significant difference from zero at p ≤0.05 and p≤0.01, respectively

Table 5. Specific combining ability (SCA) for ear number (ears ha^{-1}) of sweet corn hybrids from eight inbred lines with differences in ear size evaluated in the rainy season 2011 (a) and dry season 2011/12 (b).

(a)

Inbred	DKA	DKB1	DKB2	DKC	MS136	MS37	MS59	MS88
DKA		-1,744	-200	-5,550 **	1,081	6,963 **	-1,544	6,019 **
DKB1	2,975		-3,763 **	-1,638	4,725 **	6,250 **	-4,619 **	1,181
DKB2	-3,675	-819 **		11,219 **	-1,656	-3,844 **	-1,869	-3,175 **
DKC	150	-6,244	11,738 **		-4,713 **	2,331 *	4,850 **	-1,075
MS136	6,838 **	-1,225 **	-1,750	5,000 **		-5,438 **	5,331	2,350 *
MS37	-2,219	-419 **	-1,175 **	956 **	-1,475 *		-4,975 **	-925
MS59	150	1,725 **	-4,781	-1,781 **	14,488 **	-7,200 **		8,844 **
MS88	-2,150	544 **	-844 **	-981 **	481 *	2,963	5,950 **	

Overall mean =74,082 ears

(b)

Inbred	DKA	DKB1	DKB2	DKC	MS136	MS37	MS59	MS88
DKA		-3,050 **	-4,163 **	-6,125 **	2,900 **	-3,081 **	1,725 *	2,375 **
DKB1	2,094 **		-3,213 **	1,700 *	-1,981 *	-1,556	4,306 **	5,600 **
DKB2	1,563 **	1,650 **		1,319	-5,419 **	5,531 **	981	4,619 **
DKC	756 *	-9,700 **	844 **		5,688 **	1,463	1,531	-1,450
MS136	-4,038 *	1,894	3,656 **	-9,406		-2,569 **	-1,000	-5,594 **
MS37	-3,956 **	5,331 **	406 **	-6,300	5,513		-6,344 **	2,275 **
MS59	3,744 **	2,475 **	-6,263 *	1,013 **	2,969 **	-5,638 **		-8,531 **
MS88	1,638	975 **	6,019 **	-1,581 **	4,075 **	-4,956 **	-3,794 **	

Overall mean =78,922 ears

*, ** significant difference from zero at p ≤0.05 and p≤0.01, respectively

Table 6. Specific combining ability (SCA) for whole ear weight (kg ha $^{-1}$) of sweet corn hybrids from eight inbred lines with differences in ear size evaluated in the rainy season 2011 (a) and the dry season 2011/12 (b).

(a) Rainy season 2011

Inbred	DKA	DKB1	DKB2	DKC	MS136	MS37	MS59	MS88
DKA		-1,450 **	-2,113 **	-800 *	1,181 **	3,950 **	750	2,275 **
DKB1	1,363 **		-1,719 **	225	3,063 **	3,650 **	-244	1,481 **
DKB2	-1,606 **	-719 **		2,056 **	2,419 **	1,794 **	1,563 **	-194
DKC	-138	-350	2,319 **		806 *	2,144 **	675 *	531
MS136	2,588 **	38	381	1,275 **		-1,188 **	275	-344
MS37	-38	944 **	-656 **	738 **	-1,019 **		-281	-844 *
MS59	119	475 *	-850 **	-863 **	988 **	-1,806 **		2,006 **
MS88	75	938 **	800 **	600 **	-694 **	1,325 **	419	

Overall mean =15,299 kg

(b) Dry season 2011/12

Inbred	DKA	DKB1	DKB2	DKC	MS136	MS37	MS59	MS88
DKA		-1,150 *	-4,106 **	575	3,825 **	1,269 **	3,206 **	2,919 **
DKB1	1,688 **		-2,269 **	-513	1,663 **	3,744 **	1,513 **	4,488 **
DKB2	1,519 **	325		431	3,181 **	3,131 **	3,281 **	3,906 **
DKC	481	-2,238 **	900 *		2,325 **	2,931 **	1,025 *	3,175 **
MS136	-1,150 **	1,219 **	1,188 **	-2,788 **		138	19	-1,744 **
MS37	-3,006 **	1,163 **	194	-2,463 **	431		1,113 **	-650
MS59	2,919 **	2,013 **	-1,225 **	-844 *	-1,694 **	231		-2,925 **
MS88	3,600 **	169	3,550 **	-550	63	1,581 **	-144	

Overall mean =22,623 kg

*, ** significant difference from zero at $p \leq 0.05$ and $p \leq 0.01$, respectively

Table 7. Number of ear and whole ear weight of 28 hybrid crosses in the rainy season 2011 and dry season 2011/12.

Contrast	Number of ears (ears ha $^{-1}$)		Whole ear weight (kg ha $^{-1}$)	
	Rainy	Dry	Rainy	Dry
SxS vs. SxL	88,600 : 74,131 **	91,456 : 80,913 **	10,981 : 15,756 **	16,300 : 24,081 **
SxS vs. LxS	88,600 : 73,869 **	91,456 : 80,363 **	10,981 : 16,581 **	16,300 : 24,581 **
SxS vs. LxL	88,600 : 59,781 **	91,456 : 61,813 **	10,981 : 17,294 **	16,300 : 24,388 **
SxL vs. LxS	74,131 : 73,869	80,913 : 80,363	15,756 : 16,581 *	24,081 : 24,581
SxL vs. LxL	74,131 : 59,781 **	80,913 : 61,813 **	15,756 : 17,294 **	24,081 : 24,388
LxS vs. LxL	73,869 : 59,781 **	80,363 : 61,813 **	16,581 : 17,294 *	24,581 : 24,388

*, ** significant difference at $p \leq 0.05$ and $p \leq 0.01$, respectively

DISCUSSION

Study on combining ability is an important step of plant breeding to determine the best parents and the best hybrids. Significant differences among hybrids and inbred parents were further partitioned into GCA, SCA and reciprocal effects. Significances of GCA effects, SCA effects and reciprocals indicated that additive and non-additive gene actions control the inheritance of ear number and whole ear weight in sweet corn hybrids and maternal effects are also important in the expression of the hybrids.

In general, yield of corn comes from both high ear number and large ears. In field corn, large ear size is preferable because it is easier to harvest (better bag fill). Prolific corn (high ear number) has advantage under drought. If the first ear fails to pollinate, there is a second chance for the second ear. In vegetable corn, ear number is usually used as a commercial unit rather than ear weight. Therefore, ear number is an important strategy to increase yield in vegetable corn.

Significant interactions between corn genotype and environment for ear number and ear yield indicate that selection for superior genotypes for high ear number and high ear yield is difficult and multi location yield trails are necessary to identify the best genotypes.

Significant effect of reciprocal crosses was found for number of ear and whole ear weight. This information could be useful in selecting male and female parents with different ear sizes for hybrid seed production.

In previous studies in maize, GCA and SCA effects were important for yields (Prasad *et al.,* 1988; Sujiprhati *et al.,* 2001; Ahmad and Saleem 2003; Rana and Kapoor, 2003; Uddin *et al.,* 2006). GCA effects was also important in the inheritance of other economically important traits in maize such as ear height (Qadri *et al.,* 1983), downy mildew resistance (Kim *et al.,* 2003) and plant height (Revilla *et al.,* 1999; Mahajan *et al.* (1991), SCA effect was also important for ear height (Beck *et al.,* 1990), prolificacy in sweet corn (Younes and Andrew, 1978), grain yield (Bhatnagar *et al.,* 2004; Long *et al.,* 2004; Subramaniyan and Subbraman, 2006; Jayakumar and Sundram, 2007; Machida *et al.,* 2010), ear length and ear diameter in maize (Živanvic *et al.,* 2010).

Reciprocal effect gave small contribution to total variations in yield and other agronomic traits in maize (Pollmer *et al.,* 1979). Similarly, Mann *et al.,* (1981) and Machida *et al.,* (2010) also found that reciprocal effect had small effects on yields and quality characters in maize. The findings in this study support previous findings and also provide additional information to the whole body of the knowledge on the inheritance for ear number and whole ear weight in sweet corn.

The inbreds with high and positive GCA effects are desirable for ear number and whole ear weight, and the hybrids with high and positive SCA effects are required for these traits for further advanced evaluation in breeding program and, ultimately, for commercial release.

The results met the objective of the research, and the best inbred parents with high GCA effects for ear number and whole ear weight and the hybrids with high and positive SCA effects for these traits could be readily identified. DKA was determined as the best parent for whole ear weight, where as MS37 was determined as the best parent for number of ears. These inbred had the highest GCA effects and the means of these inbreds for these traits were also high.

Combining ability study of inbreds and populations is important for hybrid breeding in order to understand the heterotic patterns of the germplasm. Heterotic patterns in grain maize were well-established. However, less information on heterotic patterns in sweet corn is available. This study provided additional information on the heterotic pattern between sweet corn germplasm with large ears and small ears.

Theoretically, additive gene effect can be fixed in pure lines, while non-additive can be expressed in hybrids. In this study, both GCA effects and SCA effects were important for number of ears and whole ear weight. Therefore, the hybrids between DKA and MS37 should perform well for these traits. However, if non-additive effects were more important in some crosses, there would be other crosses of other inbreds that performed well.

In the hybrids of eight inbred parents, the hybrids that had either DKA or MS37 as a parent or the crosses of these parents performed well for ear number and whole ear weight. For example, MS37×DKA, MS37×DKB1 and performed well for number of ear and whole ear weight. As the parents had good combining ability for these traits, additive gene effect might contribute to the performance in these traits in the hybrids.

However, there were many hybrids of the inbreds with low combining ability for ear number and whole ear weight which also performed well for these traits. For example, DKC×DKB2 and MS88×MS56 were good hybrids for ear number in the rainy season, and MS136×DKC was a good hybrid for ear number in the dry season. For whole ear weight, MS136×DKB1, MS88×DKB1 and MS88×DKB2 were the good hybrids although their parents did not have the highest combining ability. The high performance of the hybrids of the inbred lines that did not have high combining ability for ear number and whole ear weight was possibly due to specific combining ability for these traits. The significance of reciprocal also indicated that selection of female inbreds is also important for the performance of the hybrids for ear number and whole ear weight.

The hybrids between inbreds with different ear size had higher ear number than did the hybrids of the inbreds with the same ear size. However, the hybrids between inbreds with different ear size were slightly higher than the hybrids of the inbreds with the same ear size for whole ear weight.

CONCLUSION

Ear number and whole ear weight are important traits of sweet corn, and breeding to improve these traits is a priority. The goals of this research project is to select the inbred lines with high and positive GCA effects for ear number and whole ear weight and the hybrids with high and positive SCA effects for these traits. The inbred DKA was the best parent for whole ear weight, whereas the inbred MS37 was the best parent for ear number. The hybrids that had these inbreds as parents showed good performance for these traits. However, there were other specific hybrids with high and positive SCA effects for these traits. These hybrids were selected for further evaluation in yield trials.

ACKNOWLEDGEMENTS

We are grateful for the financial support provided by the National Center for Genetic Engineering and Biotechnology, Bangkok, Thailand and Plant Breeding Research Center for Sustainable Agriculture, Faculty of Agriculture, Khon Kaen, Thailand.

REFERENCES

Ahmad A, Saleem M (2003). Combining ability analysis in *Zea mays* L. *Int. J. Agri. Biol.* 5: 239-244.

Beck DL, Vasal SK,Crossa J (1990). Heterosis and combining ability of CIMMYT's tropical early and intermediate maturity maize (*Zea mays* L.) germplasm. *Maydica* 35: 279-285.

Bhatnagar S, Betran FJ, Rooney LW (2004). Combining abilities of quality protein maize inbreds. *Crop Sci.* 44: 1997-2005.

Carey EE, Dickinson DB, Rhodes AM (1984). Sugar characteristics of sweet corn populations from a sugary enhancer breeding program. *Euphytica* 33: 609-622.

Cartea ME, Malvar RA, Revilla P, Ordas A (1996). Identification of field corn populations to improve sweet corn for Atlantic European conditions. *Crop Sci.* 36: 1506-1512.

Dewanto V, Xianzhong W, Rui HJ (2002). Processed sweet corn has higher antioxidant activity. *J. Agric. Food Chem.* 50: 4959-4964.

Dickert TE, Tracy WF (2002).Heterosis for flowering time and agronomic characters among early open-pollinated sweet corn cultivars. *J. Amer. Soc. Hort. Sci*. 127: 793-797.

Durães FOM, Magalhães PC, Oliveira AC, Santos MX, Gomes EE,Gama and Guimarães CT (2002).Combining ability of tropical maize inbred lines under drought stress conditions. *Crop Breed. Appl. Biotechnol.* 2: 291-298.

Fehr WR (1987). Principles of Cultivar Development, volume 1, Theory and technique. Macmillan Publishing Company, New York, pp. 539.

Gomez KA, Gomez AA (1984). Statistical Procedures for Agricultural Research. John Wiley and Sons. New York, pp. 680.

Griffing B (1956). Concept of general and specific combining ability in relation to diallel crossing systems. *Aust. Journ. Biol. Sci.* 9: 463-493.

Ibrahim KE, Juvik JA (2009). Feasibility for improving phytonutrient content in vegetable crops using conventional breeding strategies: case study with carotenoids and tocopherols in sweet corn and broccoli. *J. Agric. Food Chem.* 57: 4636-4644.

Jampatong S, Darrah LL, Krause GF, Barry BD (2000). Effect of one- and two-eared selection on stalk strength and other Characters in Maize. *Crop Sci.* 40: 605-611.

Jayakumar J, Sundram T (2007). Combining ability studies for grain yield and other yield components in maize. *Crop Res.* 33: 179-186.

Kesornkeaw P, Lertrat K, Suriharn B (2009). Response to four cycles of mass selection for prolificacy at low and high population densities in small ear waxy corn. *Asian J. Plant Sci.* 8: 425-432.

Kim SK, Ajala SO, Kling JG (2003). Combing ability of tropical maize germplasm in west affrica. IV. Inheritance to downy mildew (*Peronosclerospora sorghi*) infection. *Maydica* 48: 9-14.

Lertrat K, Pulam T (2007). Breeding for increased sweetness in sweet corn. *Int. J. of Plant Bred.* 1: 27-30.

Long JK, Banziger M, Smith ME (2004). Diallel analysis of grain iron and zinc density in Southern African-adapted maize inbreds. *Crop Sci.* 44: 2019-2026.

Machida L, Derera J, Tongoona P, MacRobert J (2010). Combining ability and reciprocal cross effects of elite quality protein maize inbred lines in subtropical environments *Crop Sci.* 50: 1708-1717.

Mahajan V, Khehra AS, Pal SS, Gupta AS (1991).Combining ability for growth rate characters in maize. *Crop Improv.* 18: 148-149.

Maita R, Coors JG (1996).Twenty Cycles of Biparental Mass Selection for Prolificacy in the Open-Pollinated Maize Population Golden Glow. *Crop Sci.* 36: 1527-1532.

Mann CE, Pollmer WG, Klein D (1981). Magnitude and stability over environments of reciprocal-cross differences in maize hybrids and their implications on maize breeding. *Maydica* 26: 239-252.

Matthews GA, Williams WP, Davesa CA (2007). Diallel analysis of corn earworm (Lepidoptera: Noctuidae) resistance in maize. *J. Agric. Urban Entomol.* 24: 59-66.

Pollmer WG, Klein D, Dhillon BS (1979). Differences in reciprocal crosses of maize inbred lines diverse for protein content. *Euphytica* 28: 325–328.

Prasad R, Singh S, Paroda RS (1988). Combining ability analysis in a maize diallel. *Indian J. Genet.* 48: 19-23.

Qadri MI, Agarwal KN, Sanghi AK (1983). Combining ability under two population sizes for ear characters in maize.*Indian J. Genet.Plant Breed.* 43: 208-211.

Rana MK, Kapoor V (2003). Combining ability analysis for yield and somegrowth characters in maize (*Zea Mays* L.). *Indian J. Agric. Res.* 37: 219-222.

Revilla P, Butro A, Malvar RA,Orda A (1999). Relationship among kernel weight, early vigor and growth in maize. *Crop Sci.* 39: 654-658.

Rodríguez VM, Butrón A, Sandoya G, Ordás A, Revilla P (2007). Combining maize base germplasm for cold tolerance breeding. *Crop Sci.* 47: 1467-1474.

Solomon KF, Zeppa A, Mulugeta SD (2012). Combining ability, genetic diversity and heterosis in relation to F_1 performance of tropically adapted shrunken (*sh2*) sweet corn lines. *Plant Breeding* 131: 430-436.

Subramanian A, Subbaraman N (2006). Combing ability analysis for yield and its contributing traits in maize (*Zea Mays* L.). *Indian J. Agric. Res.* 40: 131-134.

Sujiprihati SS, Saleh GB, Ali ES (2001). Combining ability of yield and related characters in single cross hybrids of tropical maize (*Zea Mays* L.). *SABRAO J. Breed. Genet.* 33: 111-120.

Uddin MS, Khatun F, Ahmed S, Ali MR, Bagum SA (2006). Heterosis and combing ability in corn (*Zea May* L.). *Bangladesh J. Bot.* 35: 109-116.

Uhr DV, Goodman MM (1995). Temperate maize inbred derived from tropical germplasm: II. Inbred yield trails. *Crop Sci.* 35: 785-790.

Ünay A, Basal H, Konak N (2004). Inheritance of grain yield in a half-diallel maize population. *Turk J. Agric For.* 28: 239-244.

Younes MH, Andrew RH (1978). Productivity and prolificacy in adiallel series of market sweet corn hybrids. *Crop Sci.* 18: 224-226.

Živanvic T, Brankovic G, Radanovic S (2010). Combing abilities of maize inbred lines for grain yield and yield components. Genetika 42: 565-574.