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Heterosis and combining ability in a diallel among elite inbred lines of maize (*Zea mays* L.)

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Abstract

Heterosis and combining ability was studied for grain yield, days to tasseling, days to silking, plant height and ear height in a diallel cross involving seven elite maize inbred lines. Variance due to GCA and SCA were highly significant for the characters studied, indicating both additive and non-additive type of gene action were important for controlling the traits. Predominance of non-additive gene action was observed for all the traits. Standard heterosis for grain yield ranged from -17.60 to 9.71%. For other traits, desirable heterosis varied from -0.10 to -4.42%; -0.03 to -4.20%; -2.44 to -42.11% and -1.33 to -21.87% for days to tasseling, days to silking, plant height and ear height, respectively. Parent Q7 was the best general combiner for higher grain yield coupled with dwarfness, and Q1 was also good general combiner for grain yield and lateness in maturity. For other traits, parent Q2, Q3 and Q4 were found suitable both for days to tasseling and silking and Q4, Q5 and Q7 for both plant and ear height showing desirable significant negative GCA effects and simultaneously possessed desirable high mean values, indicating that per se performance of the parents could prove as an useful index for combining ability. Additive × additive, additive × dominance and dominance × dominance gene interactions were involved in deriving good specific cross for yield. The cross combinations Q1 × Q7, Q2 × Q3, Q4 × Q6 and Q6 × Q7 possessing significant desirable SCA effects and high heterotic values might be used for obtaining high yielding hybrids.

Key words: Heterosis, Plant breeding, Combining ability, Maize, Quantitative breeding

Introduction

Exploitation of hybrid vigor and selection of parents based on combining ability has been used as an important breeding approach in crop improvement. Selection of parents on the basis of *per se* performance with good GCA effect is the high approach to assess the nature of gene action involved in the inheritance of character (Vasal, 1998). Combining ability analysis is one of the powerful tools in identifying the better combiners which may be hybridized to exploit heterosis and to select better crosses for direct use or further breeding work (Nigussie and Zelleke, 2001). Information on the heterotic patterns and combining ability among maize germplasm is essential in maximizing the effectiveness of hybrid development (Beck et al., 1990). Heterosis and combining ability is prerequisite for developing good economically viable hybrid variety in maize. Breeder's objectives are to select hybrids on the basis of expected level of heterosis as well as specific combining ability. The present investigation is therefore, aimed to know the gene action for yield and other important traits in maize inbred lines and to explore heterotic hybrid combinations.

Materials and Methods

Seven maize inbred lines viz. CML 487, CLG 1837, CML 480 and CML 223 originated from CIMMYT, Mexico; Ki 32 and Ki 42 from Kasrtsart Univ., Thailand and Tzi 24 from IITA, Nigeria designated as Q_1, Q_3, Q_6, Q_7, Q_2, Q_4, and Q_5 were crossed in a diallel fashion excluding reciprocals in the kharif II (rainy) season of 2005-06 with polyethylene sheed at the research farm of Bangladesh Agricultural Research Institute, Gazipur. In the following rabi (winter) season 2006-07, all the F_1 hybrids, their respective parents along with a commercial check, Pacific 11 were grown in the same farm following alpha lattice design (Patterson et al., 1978) with three replications. Each plot comprised two rows of 5 m

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long. Row to row and plant to plant spacing was 75 cm and 20 cm, respectively. One healthy seedling per hill was kept after proper thinning at two weeks after germination. Fertilizers were applied @ 250, 120, 120, 40 and 5 kg/ha of N, P_2O_5, K_2O, S and Zn, respectively. Standard agronomic practices were followed and plant protection measures were taken when required to ensure normal growth and development of the plants. Ten randomly selected competitive plants (5 from each row in a plot of each genotype in each replication) excluding any plant surrounding by a missing hill and border plants were used for recoding observations on grain yield (ton/ha), days to tasseling, days to silking, plant height (cm) and ear height (cm). Standard heteross was estimated and tested according to Singh and Singh (1994). Combining ability analysis was carried out following Model I Method 2 described by Griffing (1956) using CropStat (2007) software program. The mean squares for GCA and SCA were tested against their respective error variances derived from ANOVA reduced to mean level.

Results and Discussion

The analysis of variance showed that genotypes differed significantly for all the characters (Table 1). Analysis of variance for combining ability revealed that variance due to GCA and SCA effects were significant, indicates importance of additive as well as non-additive type of gene action. The results agree with the findings of several researchers (Mathur and Bhatnagar, 1995; Nass et al., 2000; Rokadia and Kaushik, 2005) who reported the importance of both additive and non-additive gene action in maize.

General combining ability variance (δ^2g) indicates additive (additive and additive × additive epistasis), while specific combining ability variance (δ^2s) indicates non-additive (dominance and additive × dominance, dominance × dominance) genetic variation (Griffing, 1956; Baker, 1978). So, the significant estimates of GCA and SCA variances suggest that both additive and non-additive gene actions were involved for all the characters.

The additive (σ^2A) and non-additive (σ^2D) genetic variance were estimated from GCA and SCA variances. Comparatively higher estimates of non-additive genetic variance over additive genetic variance were observed for the characters studied. Grain yield was predominantly controlled by non-additive gene action. This is corroborated with the earlier findings of Khotyleva et al. (1986) who reported that grain yield was more influenced by dominant than additive gene effects. Later on similar results were also obtained by Mathur and Bhatnagar (1995) and Zelleke (2000). Predominance of non-additive gene action for grain yield in maize was also reported by Dass et al. (1997). It could be concluded that the improvement of the characters with greater non-additive genetic component could be contemplated for the exploitation of heterosis, and with bi-parental mating.

General combining ability (GCA) effects

The estimates of GCA effects showed that none of the parent was general combiner for all the traits in desired direction (Table 2). However, parent Q_7 and Q_1 were good general combiner for grain yield. Parent Q_7 had significant negative GCA effects for plant and ear height, indicates dwarfness with low ear placement of the line. This parent possessed high mean values for grain yield and low values for plant and ear height also.

In the present study, parents were classified as high, average and low combiners based on their effects. Parents with desirable GCA effect (significantly different from zero) were considered as high combiners, while parents showing insignificant estimates were classified as average combiners. Low or poor combiners had significant but negative (undesirable) GCA effects.

Table 1. Analysis of variance for genotypic difference and combining ability for different characters in maize.

Source of variation	df	Mean of squares				
		Yield (t/ha)	Days to tasseling	Days to silking	Plant height (cm)	Ear height (cm)
Genotypes	28	2.10**	39.95**	33.75**	1115.18**	627.54**
GCA	6	1.16**	75.48**	57.20**	1461.62**	792.15**
SCA	21	2.49*	24.72**	23.70**	966.71**	556.99**
Error	56	0.07	0.91	1.10	42.556	39.89
σ^2 A	-	0.24	9.02	5.95	87.98	41.81
σ^2 D	-	1.44	14.11	13.40	547.65	306.43

*P<0.05, **P<0.01

Table 2. Estimates of GCA effects and mean values (in parenthesis) of parents for different characters in maize.

Parent/ inbred lines	Grain yield (t/ha)	Days to tasseling	Days to silking	Plant height (cm)	Ear height (cm)
Q_1	0.20*(4.12)	2.58**(83.3)	2.10**(85.3)	0.93(152.0)	-1.89(74.3)
Q_2	-0.21*(3.28)	-1.29**(84.0)	-0.61*(86.6)	-2.25(148.6)	-3.02(73.0)
Q_3	-0.26**(3.07)	-4.15**(82.6)	-3.76** (84.6)	0.69(151.0)	0.85(74.0)
Q_4	-0.06(3.38)	-0.62*(84.3)	-0.63*(87.6)	-7.18**(145.6)	-3.71*(70.0)
Q_5	0.15(3.87)	0.05(88.6)	-0.23(90.3)	-10.91**(141.3)	-3.89*(70.3)
Q_6	-0.27(3.14)	1.51**(90.3)	1.50**(93.3)	16.35**(157.6)	14.65**(76.6)
Q_7	0.46**(4.62)	1.53**(91.6)	1.24**(94.3)	-6.58**(144.0)	-8.42**(68.0)
SE *(gi)*	0.06	0.23	0.25	1.56	1.51
SE *(gi-gj)*	0.09	0.35	0.38	2.38	2.31
$LSD_{(5\%)}$	4.20	0.56	0.61	3.32	3.69

*P<0.05, **P<0.01

In case of days to tasseling and silking parents Q_2, Q_3, and Q_4 showed significant negative GCA effects and possessed low mean values for these traits. So they could be good combiner for earliness. For plant and ear height Q_4, Q_5, and Q_7 showed significant negative GCA effects and low mean values, indicates good combiner for short plant and low ear height. Negative estimates for plant and ear height are desirable. The comparison between mean performance and GCA effects of the parents showed a close relationship between them. Among the parents Q_7 was the highest yielder followed by Q_1 and these two parents also showed significant positive GCA estimates for grain yield (Table 2). Similar association between GCA and mean performance was reported by Hussain et al. (2003) and Ivy and Hawlader (2000). The parents Q_4, Q_5, and Q_7 with lower plant and ear height showed significant negative GCA effect for these traits. The good general combiners could effectively be used in future breeding program for development of high yielding hybrids with desirable traits.

Specific combining ability (SCA) effects

The estimates of SCA effects for yield and other traits are presented in Table 3. Out of 21 F_1s, seven crosses, viz. $Q_1 \times Q_2$, $Q_1 \times Q_6$, $Q_1 \times Q_7$, $Q_2 \times Q_3$, $Q_3 \times Q_4$, $Q_4 \times Q_6$ and $Q_6 \times Q_7$ showed significant positive SCA effects for yield. Positive SCA indicate that lines are in opposite heterotic groups, while negative SCA effects indicate lines are in the same heterotic group (Vasal et al., 1992). Among seven crosses, $Q_2 \times Q_3$ showed the highest positive SCA effect for yield had low × low combiners; $Q_1 \times Q_7$ had high × high; $Q_1 \times Q_6$ and $Q_6 \times Q_7$ involved of high × average; $Q_2 \times Q_5$ and $Q_3 \times Q_4$ had low × average and $Q_1 \times Q_2$ involved of high × low general combiners. Roy et al. (1998) noticed that the best crosses for yield and yield contributing characters involved of high × high, high × low, high × average and low × average general combiners for SCA effects in their study. Among seven crosses four involved of general combiners of which at least one parent was high. This result is supported by Vasal (1998), who suggested including one good combiner (especially female parent) during crossing to obtain higher heterosis. Aguiar et al. (2003) also pointed out similar opoinon that in the diallel analyses, one must select hybrids of highest specific combining ability in which one of the parental lines presents highest general combining ability. The observations of the above results indicated that additive × additive, additive × dominance and dominance × dominance gene interaction were responsible for derivation of good specific cross for higher grain yield.

For days to tasseling and silking, negative estimates are considered desirable as they are observed to be associated with earliness. Six crosses viz. $Q_1 \times Q_6$, $Q_1 \times Q_7$, $Q_2 \times Q_3$, $Q_2 \times Q_5$, $Q_3 \times Q_4$ and $Q_6 \times Q_7$ showed desirable significant negative SCA effects both for these two traits indicating to have earliness. On the other hand, five crosses viz. $Q_1 \times Q_2$, $Q_1 \times Q_3$, $Q_1 \times Q_5$, $Q_3 \times Q_4$ and $Q_4 \times Q_7$ showed desirable significant negative SCA effects both for plant and ear height, indicates dwarf type hybrids with low ear placement. In general, the GCA effects of the parents were not reflected in the SCA effects of the crosses in most of the studied traits. This result is supported by Debnath and Sarker (1987). Besides, Deitos et al. (2006) also suggested that good general combining parent does not always show high SCA effects in their hybrid combinations. The parents with good GCA for yield and negative GCA for plant and ear height and days to tasseling and silking may be extensively used in the hybridization program as a donor to obtain early and short statured hybrid with higher yield. The cross combinations showing high SCA effects for yield may be exploited.

Table 3. Estimates of SCA effects and percent standard heterosis for different characters in maize.

Cross combinations	Grain yield (t/ha)		Days to tasseling		Days to silking	
	SCA	H (%)	SCA	H (%)	SCA	H (%)
$Q_1 \times Q_2$	0.64**	3.64**	1.58**	-0.78	1.27*	0.77
$Q_1 \times Q_3$	-1.13**	-12.11**	3.78**	-1.55	3.13**	-1.16
$Q_1 \times Q_4$	-0.11	-1.33	0.18	-1.16	-0.03	-1.16
$Q_1 \times Q_5$	0.09	2.56	-0.10	-1.16	0.26	-0.39
$Q_1 \times Q_6$	0.30*	1.15	-2.56**	-2.33*	-2.47**	-1.54
$Q_1 \times Q_7$	0.33*	8.54**	-2.89**	-2.71**	-2.20**	-1.54
$Q_2 \times Q_3$	1.41**	9.71**	-4.36**	-15.50**	-4.20**	-12.36**
$Q_2 \times Q_4$	-1.88**	-17.60**	2.38**	-3.10**	3.33**	0.00
$Q_2 \times Q_5$	0.53**	1.89	-2.56**	-8.53**	-4.07**	-8.11**
$Q_2 \times Q_6$	-0.49**	-10.07**	1.31*	-2.33*	2.20**	1.16
$Q_2 \times Q_7$	-0.21	-0.36	1.64**	-1.94*	1.47**	0.00
$Q_3 \times Q_4$	0.72**	1.12	-4.42**	-14.34**	-2.80**	-11.20**
$Q_3 \times Q_5$	0.13	-0.85	1.31*	-7.36**	0.47	-6.95**
$Q_3 \times Q_6$	-0.77**	-12.20**	4.18**	-2.33*	3.40**	-1.54
$Q_3 \times Q_7$	-0.35	-1.84	-0.49	-7.75**	-0.01	-5.79**
$Q_4 \times Q_5$	0.19	0.90	0.71	-3.49**	0.01	-3.86**
$Q_4 \times Q_6$	1.17**	7.91**	-0.42	-3.10**	-1.40*	-3.47**
$Q_4 \times Q_7$	-0.09	0.56	1.58**	-0.78	0.87	-1.16
$Q_5 \times Q_6$	-0.80*	-8.79**	-1.02*	-3.49**	0.87	-0.39
$Q_5 \times Q_7$	-0.13	3.15	1.64**	-0.39	2.47**	1.16
$Q_6 \times Q_7$	0.59**	6.70**	-1.49**	-2.33*	-2.60**	-2.70**
$SE_{(ij)}$	0.12		0.45	0.93	0.49	0.85
$LSD_{(5\%)}$	7.27		0.97	1.93	1.05	1.77

Cross combi-nations	Plant height (cm)		Ear height (cm)	
	SCA	H (%)	SCA	H (%)
$Q_1 \times Q_2$	-10.51**	-13.34**	-13.33**	-24.28**
$Q_1 \times Q_3$	-11.44**	-12.42**	-12.20**	-19.94**
$Q_1 \times Q_4$	13.08**	-4.75*	14.60**	4.05
$Q_1 \times Q_5$	-12.18**	-18.10**	-8.80*	-21.10**
$Q_1 \times Q_6$	-2.44	-1.07	-5.33	-2.02
$Q_1 \times Q_7$	23.48**	0.31	25.07**	4.34
$Q_2 \times Q_3$	18.35**	-4.29*	16.60**	4.05
$Q_2 \times Q_4$	4.22	-14.42**	6.40*	-4.05
$Q_2 \times Q_5$	4.28	-16.10**	-5.67	-19.36**
$Q_2 \times Q_6$	-21.31**	-15.34**	-4.20	-2.02
$Q_2 \times Q_7$	4.96	-13.80**	0.20	-18.21**
$Q_3 \times Q_4$	-7.71*	-18.56**	-12.80**	-17.34**
$Q_3 \times Q_5$	-0.98	-17.18**	9.47**	-2.89
$Q_3 \times Q_6$	0.76	-3.83	2.93	7.51*
$Q_3 \times Q_7$	1.02	-14.26**	-4.00	-18.50**
$Q_4 \times Q_5$	11.89**	-14.88**	11.60**	-0.29
$Q_4 \times Q_6$	20.62**	1.69	2.07	7.51*
$Q_4 \times Q_7$	-42.11**	-37.73**	-21.87**	-33.24**
$Q_5 \times Q_6$	-6.64**	-12.58**	-1.33	-0.29
$Q_5 \times Q_7$	3.62	-18.40**	-5.27	-23.70**
$Q_6 \times Q_7$	9.02*	-3.37	5.86	2.02
$SE_{(ij)}$	3.07	1.94	2.98	2.74
$LSD_{(5\%)}$	6.59	4.04	6.39	5.71

*P<0.05, **P<0.01

Heterosis

Percent standard heterosis expressed by the F_1 hybrids over the check hybrid, Pacific 11 for yield and other traits are presented in Table 3. The degree of heterosis varied from cross to cross and from character to character. Heterosis ranged from -17.60 to 9.71%; -15.50 to -0.39%; -12.36 to 1.16%; -37.73 to 1.69% and -33.24 to 4.34% for grain yield, days to tasseling, days to silking, plant height and ear height, respectively.

Days to tasseling and days to silking determine the earliness or lateness of a hybrid. Negative heterosis is desirable for them. Significant negative heterosis both for days to tasseling and silking were observed in six crosses ($Q_2 \times Q_3$, $Q_2 \times Q_5$, $Q_3 \times Q_4$, $Q_3 \times Q_7$, $Q_4 \times Q_5$ and $Q_4 \times Q_6$). Earlier Maryam and Jones (1985) and Ganguli et al. (1989) reported negative heterosis for these traits in maize.

Negative heterosis is also desirable for plant height and ear height which helps for developing short statured plant leads to less lodging. Nine crosses showed significant negative heterosis for both of these traits. The highest significant negative heterosis for short plant height and low ear height was recorded by the cross $Q_4 \times Q_7$, while $Q_4 \times Q_6$ showed maximum positive heterosis for tallness and higher ear height. According to Singh (1979), generally earliness is associated with days to silking and the shorter plants with low ear height are associated with resistance to lodging.

Among the 21 F_1s, five crosses viz. $Q_1 \times Q_2$, $Q_1 \times Q_7$, $Q_2 \times Q_3$, $Q_4 \times Q_6$ and $Q_6 \times Q_7$ exhibited significant positive heterosis for grain yield. The highest heterosis 9.71% was shown by the cross $Q_2 \times Q_3$. Appreciable percentage of heterosis for grain yield in maize was also reported by Debnath (1992) and Roy et al. (1998).

From the study it can be concluded that, parents having good combining for yield (Q_1 and Q_7); earliness (Q_2, Q_3, and Q_4) and short plants (Q_4, Q_5 and Q_7) could be used as donor for obtaining high yield and desirable traits. In the present study both additive and non-additive gene actions were involved for grain yield and other traits. Therefore, for yield improvement in maize both additive and non-additive gene should be exploited through a suitable breeding program. The cross combinations $Q_1 \times Q_7$, $Q_2 \times Q_3$, $Q_4 \times Q_6$ and $Q_6 \times Q_7$ manifested significant high SCA effects coupled with excellent heterosis for yield could be used for hybrid development.

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