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COMBINING ABILITY AND HETEROSIS STUDY FOR GRAIN YIELD AND YIELD CONTRIBUTING TRAITS OF MAIZE (*Zea mays* L.)

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Abstract

The nature of combining ability and heterosis were studied in an 8×8 diallel cross excluding reciprocals in maize for grain yield and yield contributing characters. Significant estimates of general combining ability (GCA) and specific combining ability (SCA) variances suggested the importance of both additive and non-additive gene actions for the expression of the traits studied. The variances for GCA Was found significant for days to pollen shedding, days to silking, plant height, ear height, 1000- grain weight and yield. SCA was significant for all the characters except yield. Non-significant SCA variance for yield suggests that this trait was predominantly controlled by additive type of gene action. Variances due to GCA were much higher in magnitude than SCA for all the characters indicating preponderance of additive gene effects for the inheritance of these traits. Parents CML431 (P_4) and CML285 (P_6) were the best general combiner for both high yield and parent CLG1837 (P_7) and CML429 (P_8) for earliness and dwarf plant type. Seven crosses CL02450×CML451 ($P_1×P_5$), CL02450×CLG1837 ($P_1×P_7$), CML551×CML431 ($P_2×P_4$), CML223×CML451 ($P_3×P_5$), CML431×CML451 ($P_4×P_5$), CML431× CML429 ($P_4×P_8$) and CML285× CLG1837 ($P_6× P_7$) exhibited positive SCA effects for grain yield. Considering, BARI Hybrid Maize-9 (BHM-9) as check, the percent heterosis for grain yield varied from -46.17 to 12.14%. Two crosses CML551×CML431 ($P_2×P_4$) and CML285× CLG1837 ($P_6× P_7$) exhibited significant and positive heterosis 12.14 and 10.77%, respectively over the check BHM-9 suggested their benefit cost ratio (BCR) study for developing high yielding hybrid varieties.

Keywords: Maize (*Zea mays* L.), combining ability, GCA, SCA, heterosis, yield.

Introduction

Maize is one of the most important food grains in the world as well as in developing countries like Bangladesh. It is the highest yielding grain crop having various uses. A great combination of high market demand with relatively low production cost, ready market and high yield has generated great interest among the farmers in maize cultivation in Bangladesh. Day by day it is gaining popularity in the country due to vast demand, particularly for poultry industry. In

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2019-20, maize was cultivated in 11.66 lac acre of land in Bangladesh and production was 40.15 lac M.tons (BBS, 2021).

Combining ability analysis is of special importance in cross-pollinated crops helps to identifying potential parents that can be used for producing hybrids and synthetics (Vasal, 1998).

Combining ability and heterosis prerequisite for developing good economically viable hybrid variety in maize. 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. Selection of parents based on *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, 1992). Parents showing a high average combining ability in crosses are considered to have good GCA while if their potential to combine well is bounded to a particular cross, they are considered to have good SCA. Therefore, it is important to select parent with good GCA and better crosses with good SCA for development of hybrids. Hence, the investigation was undertaken to study the estimates of GCA and SCA and heterosis to develop high yielding hybrid varieties.

Materials and Methods

Eight diverse maize inbred lines *viz.* P_1(CL02450), P_2(CML551), P_3(CML223), P_4(CML431), P_5(CML451), P_6(CML285), P_7(CLG1837) and P_8(CML429) were collected from CIMMYT, India and crossed in a diallel fashion excluding the reciprocals during the *rabi* season in 2015-16. The resulting 28 F_1's were evaluated along with one check (BHM-9) in RCBD with two replications at BARI, Gazipur in the following rabi season of 2016-17. Each entry was planted in two rows of 4 m long plot. The spacing between rows was 60 cm and plant to plant distance was 25 cm.

One plant per hill was maintained after proper thinning. Data were recorded on ten randomly selected plants from each plot for plant height (cm), ear height (cm), days to pollen sheddding and silking and 1000- grain weight. Grain yield was recorded at 14% grain moisture and finally converted to ton/hectare (t/ha). Data were analyzed and the mean performances of all characters were analyzed using PB Tools software. The combining ability analysis was carried out Method IV (one set of F_1's but neither parents nor reciprocal F_1's is included) described by Griffing (1956). The mean squares for GCA and SCA were tested against error variance using the mean data of all the single cross hybrids and check variety, was estimated and tested according to Singh and Singh (1994). Percent heterosis was calculated by using the following formula:

Standard heterosis (%) = $[(\overline{F}_1 - \overline{CV})/\overline{CV}] \times 100$

Where, $\overline{F}_1$ and $\overline{CV}$ represented the mean performance of hybrid and standard check variety. The significance test for heterosis was done by using standard error of the value of check variety.

Results and Discussion

The magnitude of mean squares for GCA and SCA for studied characters (Table 1) indicated significant differences among the GCA as well as SCA effects. This also suggested presence of notable genetic variability among the genotypes for the characters studied. Highly significant differences for most of the sources of variation were also reported by Narro *et al.* (2003). The significant differences for GCA and SCA variances for different traits in maize have been reported earlier (Mathur and Bhatnagar, 1995). The mean squares of genotypes were highly significant for all the traits. This indicated an adequate amount of variability present in the materials for these traits. Further, analysis of variance for combining ability showed that estimates of mean squares due to GCA and SCA were highly significant for all the characters. This indicated importance of both additive and non-additive components of genetic variance in controlling these traits. This was supported by Debnath and Sarker (1990) and Derera *et al.* (2007) who reported similar results for yield and yield components in maize. Importance of both additive and non-additive gene effects in maize was also reported by Rokadia and Kaushik (2005).

Table 1. Mean squares due to general and specific combining ability (GCA and SCA) for six characters of maize

Sources of variation	df	Mean of squares					
		DP	DS	PH (cm)	EH (cm)	TGW (g)	GY (t/ha)
Genotype	27	18.97**	16.91**	354.92**	220.12**	1355.60**	10.50**
GCA	7	25.15**	22.11**	351.28**	225.32**	386.53**	14.76**
SCA	20	4.00**	3.67**	116.62**	65.34**	779.74**	1.92
Error	27	2.11	2.02	69.52	8.54	85.21	0.52
GCA: SCA		6.28	6.02	3.01	3.44	0.49	7.68

DP= Days to 50% pollen shedding, DS= Days to 50% silking, PH=Plant height, EH= Ear height, TGW= 1000 grain weight (g), GY= Grain Yield (t/ha). *, ** indicated at 5% and 1% level of significance, respectively.

In the present study, variances due to GCA were much higher in magnitude than SCA for all the characters indicating preponderance of additive gene effects for the inheritance of these traits. Malik *et al.* (2004) in their study also found higher GCA variances than SCA for days to pollen shedding, plant height, ear height, 1000-kernel weight and grain yield. Predominance of additive gene action for various quantitative traits in maize was also reported by Ahmed *et al.* (2008).

General combining ability (GCA) effects

The estimates of general combining ability effects of the parents are presented in Table 2. For days to pollen shedding and silking, negative estimates are considered desirable as those were observed to be associated with earliness. Data showed that the parents P_7 and P_8 showed significant and negative GCA effects for these traits. In case of plant height and ear height, negative estimates are desirable since they are correlated with shorter plant height. Parent P_7 and P_8 were good combiner having significant and negative GCA effects both for plant and ear height. According to Singh and Singh (1979), generally earliness is associated with days to silk and the shorter plants with low ear height are associated with resistance to lodging. Parents P_4 and P_6 were the best general combiner for yield and also possessed significant and positive GCA effect. This was supported by Singh *et al.* (1995) and Hussain *et al.* (2003). The overall study of GCA effects suggests that parents P_7 and P_8 were excellent general combiner for earliness, short stature and P_4 and P_6 for grain yield. These parents with desirable GCA for particular trait could be used in future breeding program to improve maize yield with desirable trait.

Table 2. General combining ability (GCA) effects for different characters

Parent	DP	DS	PH (cm)	EH (cm)	TGW(g)	GY (t/ha)
P_1	2.12**	1.72**	2.77	1.29	1.97	-0.16
P_2	-0.62	-0.60	7.02*	-2.60	-10.10**	1.22
P_3	1.12	1.39	0.02	14.07**	6.56	-1.31
P_4	0.12	0.31	9.93*	-2.32	1.97	2.37**
P_5	-0.12	-0.10	-2.22	-6.82**	11.14**	-0.73*
P_6	2.79**	2.47**	3.85	-2.54	5.31	0.77**
P_7	-3.29**	-3.18**	-8.97**	-7.85**	-7.18*	0.48
P_8	-2.12**	-2.02**	-12.39**	-8.93**	-9.68**	-2.63**
SE (gi)	0.55	0.54	3.18	3.02	3.52	0.27
$LSD_{(5\%)}$	1.08	1.06	6.23	5.92	6.90	0.53
$LSD_{(1\%)}$	1.42	1.39	8.20	7.79	9.08	0.70

*, ** indicated at 5% and 1% level of significance

Specific combining ability (SCA) effects

The SCA effects of the crosses for six characters are presented in Table 3. For days to 50% pollen shedding, three crosses exhibited significant negative SCA effects and for days to 50% silking four crosses showed significant and negative SCA, indicates early flowering of the hybrids. Considering yield, among 28 hybrids seven crosses performed significant and positive SCA effects for grain yield (Table 3). Out of 28 crosses, seven crosses $P_1 \times P_5$, $P_1 \times P_7$, $P_2 \times P_4$, $P_3 \times P_5$, $P_4 \times P_5$, $P_4 \times P_8$ and $P_6 \times P_7$ showed significant and positive SCA effects for yield. The significant and positive SCA effect involved parents where one or both the parents were related to good combiners, indicating GCA of the parental lines plays a key role for high yield. Xingming *et al.* (2002) also reported similar conclusion. Vasal (1998) also suggested to include one good combiner (especially female parent) during crossing to obtain higher heterosis.

Table 3. Specific combining ability (SCA) effects for different characters in 8×8 diallel cross in maize

Crosses	DP	DS	PH (cm)	EH (cm)	TGW (g)	GY (t/ha)
$P_1 \times P_2$	1.32	1.00	-16.20*	-18.49**	32.32**	-0.79**
$P_1 \times P_3$	-2.42*	-2.5*	17.79*	-3.49	-34.34**	-0.27
$P_1 \times P_4$	1.07	1.08	-14.11*	4.90	45.23**	-1.02**
$P_1 \times P_5$	-1.67	-1.5	12.54	-7.60	-21.42**	0.93**
$P_1 \times P_6$	-1.09	-1.08	1.96	10.45	-23.09**	0.07
$P_1 \times P_7$	1.49	1.08	-0.70	1.73	-10.59**	0.70**
$P_1 \times P_8$	1.32	1.91	-1.28	2.51	11.90**	0.37
$P_2 \times P_3$	0.32	-0.16	-3.95	-1.94	-22.26**	-0.11
$P_2 \times P_4$	1.32	1.41	-6.86	-2.88	2.32	0.74**
$P_2 \times P_5$	-0.42	-0.66	9.79	19.95	13.15**	0.04
$P_2 \times P_6$	2.65	2.75	2.21	-4.66	-21.01**	0.31
$P_2 \times P_7$	-3.26**	-2.58*	12.54	2.29	-1.01	-0.17
$P_2 \times P_8$	-1.92	-1.75	1.46	-4.27	-3.51	-0.01
$P_3 \times P_4$	-0.92	1.08	-5.36	2.45	5.65	-1.21**
$P_3 \times P_5$	2.32	2.33	0.29	7.95	-13.51**	1.82**
$P_3 \times P_6$	-2.09	-1.25	5.21	0.01	42.32**	0.41
$P_3 \times P_7$	1.99	1.91	-9.95	3.95	-15.17**	-0.32

Table 3. Cont'd

Crosses	DP	DS	PH (cm)	EH (cm)	TGW (g)	GY (t/ha)
$P_3 \times P_8$	0.32	0.75	-4.03	-8.94	37.32**	-0.31
$P_4 \times P_5$	-0.67	-1.08	-14.88*	-21.33**	-13.92**	0.98**
$P_4 \times P_6$	-3.09*	-2.66*	0.79	-0.60	-35.59**	-0.01
$P_4 \times P_7$	1.99	2.50*	-0.36	10.01	1.90	-1.43**
$P_4 \times P_8$	0.32	-0.16	21.04**	7.45	-5.59	1.94**
$P_5 \times P_6$	1.15	0.75	-14.03**	-15.56*	42.73**	-3.38**
$P_5 \times P_7$	-0.76	-0.58	-5.70	-2.49	27.73**	-0.21
$P_5 \times P_8$	0.07	0.75	-7.78	-2.05	-34.76**	-0.19
$P_6 \times P_7$	0.82	0.33	-8.21	-15.77**	-1.42	2.92**
$P_6 \times P_8$	1.65	1.16	-4.3	-5.01	-3.92	-0.32
$P_7 \times P_8$	-2.26	-2.66**	-5.03	0.29	-1.42	-1.40**
SE(ij)	1.22	1.20	7.04	6.70	3.52	0.27
LSD $_{(5\%)}$	2.39	2.35	13.80	13.13	6.90	0.53
LSD $_{(1\%)}$	3.15	3.10	18.16	17.29	9.08	0.70

*, ** indicated at 5% and 1% level of significance; DP = Days to 50% shedding, DS = Days to 50% silking, PH = Plant height, EH = Ear height, TGW = Thousand grain weight, GY = Grain yield.

The desirable significant SCA effects observed for different characters were exhibited by the crosses involved high × average, high × low and low × low general combining parents. High SCA effects manifested by different crosses were of good combiner parents might be attributed to sizeable additive × additive gene action. The high × low combinations, besides expressing the favorable additive effect of the high parent, manifested some complementary gene interaction effects with a higher SCA. An appreciable amount of the SCA effects expressed by low × low crosses might be attributed to dominance × dominance type of non-allelic gene action produced over dominance and are non-fixable. It appears that superior performance of most hybrids may be largely due to epistatic interaction. The SCA effects of the crosses exhibited no specific trends in cross combinations between parents having high, medium and low GCA effects. So, the crosses which showing desirable SCA effects can be used in future breeding program.

Heterosis

The standard heterosis expressed by the F_1 hybrids over the standard check BHM-9 for different characters are presented in Table 4. The percent of heterosis in F_1 hybrids varied from character to character and from cross to cross.

Days to pollen shedding (DP) and days to silking (DS)

Days to pollen shedding and silking determine the earliness of flowering of the hybrid. Negative heterosis is desirable for these characters. Considering hybrid BHM-9 as a check, two crosses showed significant and negative heterosis for days to pollen shedding and ranged from -4.88 to 10.98%. For days to silking, two crosses showed significant and negative heterosis and ranged from -4.71 to 10.59% (Table 4).

Plant height (PH) and ear height (EH)

Negative heterosis is desirable for plant height and ear height which helps for developing short statured plant leads to less lodging. Considering hybrid BHM-9 as a check all of the 28 crosses exhibited significant and negative heterosis for plant height indicates dwarfness of the hybrids which ranged from -35.03 to -8.47% (Table 4). For ear height, twelve crosses showed significant and negative heterosis (Table 4).

1000- grain weight (TGW)

Positive heterosis is also desirable for bold grain hybrids. Considering grain weight, five crosses expressed significant and positive heterosis ranged from -14.01 to 9.24% (Table 4).

Table 4. Percent heterosis over the check variety BHM-9 for different characters in 8×8 diallel crosses of maize

Crosses	DP	DS	PH (cm)	EH (cm)	TGW (g)	GY (t/ha)
$P_1 \times P_2$	8.54**	7.06**	-23.73**	-32.76**	2.24	-23.00**
$P_1 \times P_3$	7.32**	4.71**	-8.47**	1.72	-11.76**	-40.40**
$P_1 \times P_4$	8.54**	8.24**	-20.90**	0.00	9.24**	-15.07**
$P_1 \times P_5$	6.10**	4.71**	-12.43**	8.62*	-7.00**	-24.98**
$P_1 \times P_6$	9.76**	8.24**	-15.25**	13.79**	-8.96**	-19.38**
$P_1 \times P_7$	4.88**	3.53**	-23.73**	3.45	-8.96**	-16.45**
$P_1 \times P_8$	6.10**	5.88**	-25.99**	-10.34**	-3.36*	-46.17**
$P_2 \times P_3$	6.10**	4.71**	-18.08**	-18.97**	-11.76**	-27.05**
$P_2 \times P_4$	6.10**	5.88**	-14.12**	8.62*	-6.16**	12.14**
$P_2 \times P_5$	3.66**	2.35**	-11.86**	3.45	-0.56	-20.71**
$P_2 \times P_6$	10.98**	10.59**	-12.43**	-3.45	-11.76**	-5.34**
$P_2 \times P_7$	-3.66**	-2.35**	-13.56**	3.45	-9.80**	-12.06**
$P_2 \times P_8$	0.00	-1.18	-22.03**	-12.07**	-11.20**	-37.64**

Table 4. Cont'd.

Crosses	DP	DS	PH (cm)	EH (cm)	TGW (g)	GY (t/ha)
P_3×P_4	4.88**	4.71**	-17.51**	0.00	-0.56	-32.90**
P_3×P_5	8.54**	9.41**	-20.90**	-31.03**	-3.36*	-21.02**
P_3×P_6	7.32**	8.24**	-14.69**	3.45	5.04**	-26.27**
P_3×P_7	4.88**	4.71**	-30.51**	-32.76**	-8.96**	-35.23**
P_3×P_8	4.88**	4.71**	-29.38**	-22.41**	5.04**	-38.76**
P_4×P_5	4.88**	3.53**	-12.99**	24.14**	-4.76**	-2.67
P_4×P_6	4.88**	4.71**	-11.86**	6.90	-12.61**	1.81
P_4×P_7	3.66**	3.53**	-19.77**	5.17	-5.60**	-13.09**
P_4×P_8	2.44**	2.35**	-9.60**	12.07**	-8.40*	-10.77**
P_5×P_6	9.76**	8.24**	-27.12**	-24.14**	7.84**	-43.15**
P_5×P_7	0.00	0.00	-29.38**	-37.93**	3.64**	-29.29**
P_5×P_8	2.44**	2.35**	-32.77**	-43.10**	-14.01**	-37.90**
P_6×P_7	6.10**	3.53**	-18.08**	-10.34**	-5.60**	10.77**
P_6×P_8	7.32**	5.88**	-27.12**	-34.48**	-7.00**	-40.14**
P_7×P_8	-4.88**	-4.71**	-35.03**	-32.76**	-9.80**	-36.09**
Mean	5.05	4.41	-19.97	-8.99	-4.96	-22.53
Min	-4.88	-4.71	-35.03	-43.10	-14.01	-46.17
Max	10.98	10.59	-8.47	24.14	9.24	12.14
SE	0.71	0.66	1.42	3.53	1.24	3.03
$CD_{(0.05)}$	1.46	1.36	2.91	7.24	2.55	6.21
$CD_{(0.01)}$	1.96	1.83	3.93	9.78	3.45	8.38

*, ** indicated at 5% and 1% level of significance, DP = Days to 50% shedding, DS = Days to 50% silking, PH = Plant height, EH = Ear height, TGW = Thousand grain weight, GY = Grain yield.

Grain yield (GY)

The percent heterosis for kernel yield varied from -46.17 to 12.14%. Talukder *et al*. (2016) also found -51.39 to 12.53% heterosis in their study. It showed that among the 28 F_1s, two crosses exhibited significant and positive heterosis for grain yield (Table 4). The highest heterosis was exhibited by the cross P_2×P_4 (12.14%) and followed by P_6×P_7 (10.77%).

Conclusion

Parents with positive GCA for high yield (P_4 and P_6), for early flowering and short duration, short plant and ear height (P_7 andP_8) and for bold grain weight (P_5) can be used as donor for combining high yield with desirable traits. Seven crosses $P_1 \times P_5$, $P_1 \times P_7$, $P_2 \times P_4$, $P_3 \times P_5$, $P_4 \times P_5$, $P_4 \times P_8$ and $P_6 \times P_7$ exhibited positive SCA effects for grain yield. Two crosses ($P_2 \times P_4$ and $P_6 \times P_7$) showed significant and positive heterosis for yield compared to the check variety BHM-9. The cross combinations manifested significant high SCA effects coupled with *per se* performance and could be more rewarding in a hybrid breeding program after intensive investigation at different agro ecological zones.

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