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HETEROSIS AND COMBINING ABILITY ANALYSIS IN MAIZE USING LINE X TESTER MODEL

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Abstract

Twenty-two lines were crossed with 2 testers in a Line × Tester mating design in 2017-18 and the resulting 44 crosses along with the lines, testers and three checks i.e., BARI Hybrid Maize 9 (BHM 9), 981 and Elite were evaluated in a alpha lattice design with two replications, during rabi, 2018-19. Highly significant differences were found among the genotypes for all the characters studied. Parent and parents vs crosses were significant for all the characters except ASI indicating greater diversity in the parental lines of the traits. Three lines (viz., BMZ 55, BMZ 53, BMZ 4) showed significant negative GCA effect for both days to 50% tasseling and silking, indicating good general combiners for earliness. BMZ 15, BMZ 55, BMZ 53 and BMZ 68 showed significant negative GCA effects for both plant and ear height. BIL 79, Pinacle 17 and BIL 182 exhibited desirable significant positive GCA for grain yield. Considering desirable GCA effects those parents could be used extensively in hybrid breeding program to accumulate those favorable genes. However, two cross combinations BIL 182 x CML 429 and BIL 79 x CML 429 were found promising considering SCA effect, mean performance and could be utilized for enhancing hybrid production. Considering BHM 9 as check, the percent standard heterosis for grain yield varied from -52.6 to 0.6%. None of the crosses showed significant positive heterosis for grain yield except BIL 79 × CML 429.

Keywords: General Combining Ability (GCA), Specific Combining Ability (SCA), Heterosis, maize.

Introduction

Maize (*Zea mays* L.) is a versatile crop with wider genetic variability and able to grow successfully throughout the world covering tropical, subtropical and temperate agro-climatic conditions. Maize acreage and production have an increasing tendency with the introduction of hybrids due to its high yield potential. Efforts are, therefore, required to be made to develop hybrids with high yield potential to increase production of maize. Most efficient use of such materials would be possible only when adequate information on the amount and type of genetic variation and combining ability effects in the materials is available. Heterosis and combining ability is prerequisite for developing a good

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economically viable hybrid maize variety. Combining ability analysis is useful to assess the potential inbred lines and helps in identifying the nature of gene action involved in various quantitative characters. Combining ability is dissected into two parts general combining ability (GCA) and specific combining ability (SCA). Both GCA and SCA variances have been determined and related to the possible types of gene action involved. GCA is a good estimate of additive gene action, whereas SCA is a measure of non-additive gene action (Sharief *et al.*, 2009). This information is helpful to plant breeders for formulating hybrid breeding programmes. A wide array of biometrical tools is available to breeders for characterizing genetic control of economically important traits as a guide to decide upon an appropriate breeding methodology to involve in hybrid breeding. Line × tester mating design developed by Kempthorne (1957), which provides reliable information on the general and specific combining ability effects of parents and their hybrid combinations was used to generate the information. The design has been widely used in maize by several workers like, Joshi et al. (2002) and Sharma *et al.*, (2004) and continues to be applied in quantitative genetic studies. The line×tester analysis provides information on GCA of parents and specific combining ability (SCA) of hybrids which helps to identify good quality inbreds and hybrids, respectively (Silva *et al.*, 2010; Moterle *et al.*, 2011). The present investigation was carried out to determine the nature and magnitude of gene action for yield and other important traits in maize.

Materials and Methods

The experiment was conducted during rabi season, 2018-2019 at the experimental field of Plant breeding division of Bangladesh Agricultural Research Institute (BARI), Gazipur. The institute is located at 23°59’ N latitude and 90°25’ E longitude. The climate of the area is characterized as tropical with mean monthly maximum and minimum temperature of 28.9°C and 18.8°C, respectively. The soil of the experimental field of BARI, Gazipur is characterized by sandy loam with 62.72% sand, 21.95% silt and 15.33% clay. The soil of the field is slightly acidic to neutral and thus pH varied from 6.1 to 6.9. The organic matter content of the soil is also low which was only1.34% and available phosphorous (P) content is 14.60 ppm. A total of forty-seven (47) entries including 44 test crosses produced by crossing twenty-two elite inbred lines with two testers (CML 429 and CML 425) and three standard checks (BARI Hybrid Maize 9, 981, Elite) were used in this experiment. The lines were obtained from PBD, BARI, but some are originally introduced from CIMMYT breeding program.

The experiment was laid out in alpha lattice design with two replications having plot consisted of two rows of 4-meter lengths with row-to-row distance of 60 cm and plant to plant of 25 cm. Two seeds were planted per hill on 26th of November 2018 and later thinned out to one plant per hill after seedlings were well established. Fertilizers were applied @ 250, 55, 110, 40, 5 and 1.5 kg/ha of N, P, K, S, Zn and B respectively. Other standard agronomic practices like weeding and pest management have been done manually throughout the entire growing season as required. Data were collected on days to tasseling (DT): number of days from planting to 50% of the plants in a plot shed pollen, days to silking (DS): Number of days from planting to 50% of the plants in a plot produced 2-3 cm long silk, plant height (PH): the average height of five randomly selected plants measured in cm from base of the plant to the first tassel branch, ear height (EH): the average height of five randomly selected plants measured in cm from base of the plant to the node bearing the upper most ear of the same plants used to measure plant height, anthesis silking interval(ASI): number of days interval between days to anthesis or tasseling (DT) and days to silking (DS),grain yield (GY): total grain yield in kg per plot and adjusted to 12.5% moisture level and converted to t/ha.

The data were analyzed for combining ability as per procedure given by Kempthorne (1957). The mean performances of all characters were analyzed using Crop Stat software. Data were analyzed for variance for all the characters studied. Using the mean data of all the single cross hybrid and check variety, the standard heterosis (against the BHM 9; standard check hybrid variety) was estimated and tested. Percent heterosis was calculated by using the following formula:

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

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

Results and Discussion

The analysis of variance for different characters is presented in Table 1 which indicated that there were highly significant differences among the genotypes for all the characters. ANOVA partitioned the variance into cross/hybrid variance, line variance, tester variance and line × tester variance. All the variance revealed that there were significant differences in all the characters. Similarly, parent and parent's vs crosses were significant for all the characters except ASI indicating greater diversity in the parental lines of the traits. The present observations are in agreement with the earlier report Ali *et.al.* (2012). A comparison of the magnitude of variance components due to GCA and SCA confirms the gene action in controlling the expression of traits. The ratio of GCA and SCA variance for all the traits were less than one, which indicates that all these characters were predominantly governed by non-additive gene effects (Table 1). Similar findings were reported by Kanagarasu *et al.* (2010) and Kumar *et al.* (2014) for grain yield, cob length, plant height, ear height, 100 grain weight, grain rows per cob, days to 50 per cent tassel and days to 50 per cent silk and Ali *et al.* (2012) for number of grain rows per cob and 100-grain weight in maize in their study.

Table 1. Mean squares and estimates of variance for grain yield and yield components in maize evaluated at Gazipur during *rabi* 2018-19

Sources	df	DT (days)	DS (days)	PH (cm)	EH (cm)	ASI (days)	Y (t/ha)
Genotypes	67	116.51**	112.54**	2752.89**	787.93**	2.88**	17.58**
Parents	23	37.08**	38.04**	1379.12**	488.52**	1.03	0.60
P vs C	1	5897.97**	5749.76**	133049.84**	31238.30**	0.94	941.32**
Crosses	43	24.55**	21.29**	457.54**	239.94**	3.91**	5.18**
Lines	21	36.75**	34.85**	791.29**	395.55**	4.68**	7.34**
Testers	1	145.10**	39.56**	125.28	166.38**	33.14**	31.66**
Lines x Testers	21	6.60	6.87	139.62	87.83	1.76	1.76*
Error	67	7.85	9.17	95.61	74.21	1.22	0.90
Estimate of component of variance							
σ^2 g (line)		7.54	7.00	162.92	76.93	0.73	1.39
σ^2 g (tester)		3.15	0.74	-0.32	1.79	0.71	0.68
σ^2gca		0.27	0.22	4.85	2.32	0.03	0.05
σ^2sca		-0.62	-1.15	22.00	6.81	0.27	0.43
σ^2gca/ σ^2sca		-0.43	-0.19	0.22	0.34	0.11	0.11

* Significant at 5% level, ** Significant at 1% level.

DT=days to 50% tasseling, DS=days to 50% silking, PH=plant height, EH=ear height, ASI= anthesis silk interval, Y= yield.

The proportional contributions of lines (female), testers (male) and their interactions (crosses) to total variance for different traits revealed that female lines (maternal) contributed much higher compared to male lines (paternal) in all studied traits (Table 2). Results showed that maternal parents play the most important role for those traits. Similar conclusion was reported by Amiruzzaman (2010) who observed the greater effect of female lines for grain yield and other traits.

Table 2. Proportional contribution of lines, testers and their interactions to total variance in maize

Sources	DT (days)	DS (days)	PH (cm)	EH (cm)	ASI (days)	Y (t/ha)
Line (L)	73.12	79.93	84.46	80.51	58.40	69.18
Tester (T)	13.75	4.32	0.64	1.61	19.69	14.22
Line x Tester	13.14	15.75	14.90	17.88	21.91	16.60

DT=Days to Tassel, DS=Days to Silk, PH=Plant Height, EH= Ear Height, ASI= anthesis silk interval

General combining ability (GCA) effects

The general combining ability (GCA) effects of lines (females) and testers (males) are presented in Table 3. Among the parents, three lines (viz., BMZ 55, BMZ 53, BMZ 4) showed significant and negative GCA effect for both days to 50% tasseling and silking, indicating good general combiners for earliness. Bhavana *et al*. (2011) and Jawaharlal *et al*. (2012) also reported the additive gene action for days to 50 per cent tassel and silk. Lines BMZ 15, BMZ 55, BMZ 53 and BMZ 68 showed significant and negative GCA effects for both plant and ear height. The lines (BMZ 55, BMZ 53) also recorded negative GCA effect for days to tasseling, and silking indicated that these parents were suitable for earliness and/or short stature breeding. Similar observations in maize were reported by Motamedi *et al.* (2014) and Premlatha and Kalamani (2010). Three parental lines (BIL 79, Pinacle 17 and BIL 182) exhibited desirable significant positive GCA for grain yield. These lines could be desirable parents for hybrids as well as for inclusion in breeding program, since they may contribute favourable alleles in the synthesis of new varieties. The parents exhibited significant and positive GCA for yield, were good general combiner and those could be used for exploiting more positive alleles for yield (Table 3). Significant GCA effect for yield in maize was also reported by Amin *et al.* (2014), Kumar *et al.* (2014), Ivy and Hawlader (2000) and Amiruzzaman (2010). As GCA is generally associated with additive gene action in inheritance of characters, the lines with high GCA may be utilized in hybridization program to improve a particular trait through transgressive segregation.

Specific combining ability (SCA) effects

The Specific combining ability effects are presented in the Table 4. In respect of days to tassel and days to silk, no cross combination recorded significant and negative SCA effects. In case of maize, significant and negative value is expected for plant and ear height to develop short stature plant. The lowest days for 50% tasseling and silking was found in the cross BMZ 53 × CML 425. Lowest plant height and ear height was observed in cross BMZ15 × CML 425. Positive SCA effect is expected for yield and yield components. In case of grain yield, only one cross (CML 451 × CML 429) exhibited significant positive SCA effects. Among the cross combination highest yield (13.3 t/ha) was produced by BIL 79 × CML 429 followed by BIL 182 × CML 429 (12.6 t/ha).

Table 3. General combining ability (GCA) effects and mean of parents for grain yield and yield components and other characters in maize

Parents	DT (days)		DS (days)		PH (cm)		EH (cm)		ASI (days)		Y (t/ha)	
	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean
Testers												
1.CML 429	1.28**	94	0.67	99	1.19	83	-1.38	42	-0.61**	5	0.60**	4.0
2.CML 425	-1.28**	83	-0.67	87	-1.19	99	1.38	55	0.61**	4	-0.60**	4.6
SE (gi)	0.42		0.46		1.47		1.30		0.17		0.14	
SE (gi-gj)	0.60		0.65		2.08		1.84		0.24		0.20	
Lines												
1. Pinacle 20	-1.011	98	-1.85	104	8.22	106	0.81	44	-0.84	6	0.19	4.6
2. BMZ 15	-5.261**	98	4.60**	103	-22.28**	79	-14.19**	27	0.66	5	-1.93**	3.5
3. BIL 79	3.239*	99	1.90	104	17.72**	124	9.06*	66	-1.34*	6	2.92**	4.8
4. Pinacle 17	1.989	101	3.15*	104	-6.78	89	-6.19	40	1.16*	4	2.59**	3.6
5. BMZ 55	-4.761**	95	-3.35*	100	-21.28**	57	-15.19**	28	1.41*	5	-1.11*	3.6
6. Pinacle 10	4.239**	101	3.40*	105	-1.53	81	1.06	36	-0.84	4	0.85	3.8
7. Pinacle 12	-0.761	100	0.15	104	16.97**	95	9.06*	45	0.91	4	0.46	4.0
8. BMZ 68	-3.761**	98	-2.85	101	-17.78**	80	-9.69*	33	0.91	4	-0.01	3.4
9. CML 481	4.239**	100	5.40**	104	6.97	69	11.81**	29	1.16*	4	-1.07*	3.5
10. CML 451	1.989	97	3.90*	101	-1.03	122	-4.94	73	1.91**	4	-0.08	4.7

Table 3. Continued

Parents	DT (days)		DS (days)		PH (cm)		EH (cm)		ASI (days)		Y (t/ha)	
	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean
11. BMZ 25	1.739	100	1.15	105	-9.28	48	0.56	19	-0.59	5	-0.07	3.7
12 BMZ 56	-1.011	97	0.15	103	-2.78	88	-3.44	35	1.16*	6	-1.96**	3.5
13. BMZ 53	-4.261**	96	-4.35**	99	-16.03**	58	-16.94**	22	-0.09	4	-0.63	3.6
14. BMZ 4	-3.761**	94	-4.35**	99	-14.28**	48	-7.69	22	-0.59	5	-1.22**	3.6
15. 900M 1	-0.011	103	-0.85	109	-7.03	120	-0.69	52	-0.84	6	-0.40	4.9
16. 900M 4	3.489*	103	3.15*	107	24.72**	92	15.81**	30	-0.34	4	0.67	4.0
17. CML 496	3.989**	105	2.65	109	22.72**	94	21.06**	33	-1.34*	5	0.64	4.0
18. BIL 182	-1.011	99	-2.10	102	-4.03	76	-1.44	37	-1.09	4	2.38**	3.7
19. Pinacle 3	-1.511	101	-2.35	105	8.47	94	-4.19	32	-0.84	4	-0.80	4.1
20. CML 487	-0.511	97	-0.10	102	-5.03	83	0.81	26	0.41	5	-1.13*	3.8
21. 900M 10	0.739	101	1.65	106	10.72*	99	6.06	45	0.91	5	-1.10*	4.2
22. E 34	1.989	100	0.15	104	12.72*	165	8.56	77	-1.84**	4	0.78	5.5
SE (gi)	1.40		1.51		4.89		4.31		0.55		0.47	
SE (gi-gj)	1.98		2.14		6.91		6.09		0.78		0.67	

* Significant at 5% level, ** Significant at 1% level.

DT=Days to Tassel, DS=Days to Silk, PH=Plant Height, EH= Ear Height, ASI= Anthesis silking interval, Y=Yield.

Table 4. Specific combining ability (SCA) effects and mean of the crosses for grain yield and yield contributing characters in maize

Crosses	DT (days)		DS (days)		PH (cm)		EH (cm)		ASI (days)		Y (t/ha)	
	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean
1.Pinacle 20 × CML 429	-1.53	83	-1.17	87	-8.69	156	-2.875	68	0.36	4	-1.04	9.3
2.Pinacle 20 × CML 425	1.53	84	1.17	88	8.69	171	2.875	76	-0.36	4	1.04	10.1
3.BMZ 15 × CML 429	0.22	81	0.58	86	4.81	139	3.125	59	0.36	5	-0.78	7.4
4.BMZ 15 × CML 425	-0.22	78	-0.58	83	-4.81	127	-3.125	55	-0.36	6	0.78	7.8
5.BIL 79 × CML 429	-0.28	89	0.08	92	0.31	174	-1.625	77	0.36	3	0.24	13.3
6.BIL 79 × CML 425	0.28	87	-0.08	90	-0.31	171	1.625	83	-0.36	4	-0.24	11.6
7.Pinacle 17 × CML 429	0.47	88	1.33	94	-3.19	146	2.125	66	0.86	6	-0.82	11.9
8.Pinacle 17 × CML 425	-0.47	85	-1.33	90	3.19	150	-2.125	64	-0.86	6	0.82	12.3
9.BMZ 55 × CML 429	-0.28	81	-0.17	86	7.81	143	6.625	61	0.11	6	-0.25	8.7
10.BMZ 55 × CML 425	0.28	79	0.17	85	-7.81	125	-6.625	51	-0.11	7	0.25	8.0
11.Pinacle 10 × CML 429	1.72	92	1.58	95	-10.44	144	-10.125	61	-0.14	3	-1.12	9.8
12.Pinacle 10 × CML 425	-1.72	86	-1.58	90	10.44	163	10.125	84	0.14	5	1.12	10.9
13.Pinacle 12 × CML 429	1.22	86	1.83	92	-4.44	169	-5.625	73	0.61	6	-0.93	9.6
14.Pinacle 12 × CML 425	-1.22	81	-1.83	87	4.44	175	5.625	87	-0.61	6	0.93	10.3
15.BMZ 68 × CML 429	2.72	85	1.83	89	-3.69	135	-6.375	54	-0.89	4	-0.42	9.7
16.BMZ 68 × CML 425	-2.72	77	-1.83	84	3.69	140	6.375	69	0.89	7	0.42	9.3
17.CML 481 × CML 429	0.72	91	-0.92	94	-6.44	157	3.625	85	-1.64*	4	0.34	9.4
18.CML 481 × CML 425	-0.72	87	0.92	95	6.44	167	-3.625	81	1.64*	8	-0.34	7.5
19.CML 451 × CML 429	-0.53	87	-0.42	93	6.06	161	5.875	71	0.11	6	1.29*	11.3
20.CML 451 × CML 425	0.53	86	0.42	93	-6.06	147	-5.875	62	-0.11	7	-1.29*	7.5
21.BMZ 25 × CML 429	-1.28	86	-1.17	90	3.81	151	-6.125	64	0.11	4	-0.09	10.0
22.BMZ 25 × CML 425	1.28	86	1.17	91	-3.81	141	6.125	79	-0.11	5	0.09	8.9

* Significant at 5% level, ** Significant at 1% level.

DT=Days to Tassel, DS=Days to Silk, PH=Plant Height, EH= Ear Height, ASI= Anthesis silking interval, Y=Yield.

Table 4. Continued

Crosses	DT (days)		DS (days)		PH (cm)		EH (cm)		ASI (days)		Y (t/ha)	
	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean
23. BMZ 56 x CML 429	-2.03	83	-3.67	86	14.31*	168	6.375	73	-1.64*	4	0.67	8.8
24. BMZ 56 x CML 425	2.03	84	3.67	92	-14.31*	137	-6.375	63	1.64*	8	-0.67	6.3
25. BMZ 53 x CML 429	1.72	83	1.33	87	2.06	142	2.875	56	-0.39	4	0.25	9.7
26. BMZ 53 x CML 425	-1.72	77	-1.33	83	-2.06	136	-2.875	53	0.39	6	-0.25	8.0
27. BMZ 4 x CML 429	-0.28	82	-0.17	85	2.81	145	1.625	64	0.11	4	0.79	9.7
28. BMZ 4 x CML 425	0.28	80	0.17	84	-2.81	137	-1.625	63	-0.11	5	-0.79	6.9
29. 900M 1 x CML 429	-1.53	84	-1.17	88	-4.44	145	-3.875	65	0.36	4	0.31	10.0
30. 900M 1 x CML 425	1.53	85	1.17	89	4.44	151	3.875	76	-0.36	4	-0.31	8.2
31. 900M 4 x CML 429	0.47	90	0.83	94	-3.69	177	-3.875	82	0.36	4	1.08	11.9
32. 900M 4 x CML 425	-0.47	86	-0.83	91	3.69	182	3.875	92	-0.36	5	-1.08	8.5
33. CML 496 x CML 429	-0.53	89	-0.17	92	-0.19	179	-3.125	88	0.36	3	0.17	10.9
34. CML 496 x CML 425	0.53	88	0.17	91	0.19	177	3.125	97	-0.36	4	-0.17	9.4
35. BIL 182 x CML 429	0.47	85	0.58	88	5.56	158	2.375	71	0.11	3	0.06	12.6
36. BIL 182 x CML 425	-0.47	82	-0.58	86	-5.56	144	-2.375	69	-0.11	4	-0.06	11.2
37. Pinacle 3 x CML 429	-1.03	83	-0.67	87	-5.44	159	1.625	67	0.36	4	0.45	9.8

Table 4. Continued

Crosses	DT (days)		DS (days)		PH (cm)		EH (cm)		ASI (days)		Y (t/ha)	
	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean
38. Pinacle 3 x CML 425	1.03	83	0.67	87	5.44	168	-1.625	67	-0.36	4	-0.45	7.7
39. CML 487 x CML 429	-2.03	83	-1.42	88	3.56	155	0.125	71	0.61	5	-0.19	8.8
40. CML 487 x CML 425	2.03	85	1.42	90	-3.56	145	-0.125	73	-0.61	5	0.19	8.0
41. 900M 10 x CML 429	0.22	87	0.33	92	1.31	168	5.375	81	0.11	5	-0.10	8.9
42. 900M 10 x CML 425	-0.22	84	-0.33	90	-1.31	163	-5.375	73	-0.11	6	0.10	7.9
43. E 34 x CML 429	1.47	89	0.83	91	-1.69	167	1.875	80	-0.64	2	0.11	11.0
44.E 34 x CML 425	-1.47	84	-0.83	88	1.69	168	-1.875	79	0.64	4	-0.11	9.6
45.BHM 9(check 1)		85		91		195		90		6		14.19
46.981(check 2)		87		95		197		92		8		12.76
47.Elite (check 3)		86		93		184		80		8		14.05
$SE_{(Sij)}$	1.98		2.14		6.91		6.09		0.78		0.61	
$SE_{(Sij-Skl)}$	2.80		3.03		9.78		8.61		1.11		0.95	

* Significant at 5% level, ** Significant at 1% level.

DT=Days to Tassel, DS=Days to Silk, PH=Plant Height, EH= Ear Height, ASI= Anthesis silking interval, Y=Yield.

Heterosis

The percent standard heterosis expressed by F_1 hybrids over the commercial hybrid check variety BHM9 for yield and different yield contributing characters are presented in Table 5. The degree of heterosis in F_1 hybrids varied from character to character or from cross to cross.

Table 5. Percent heterosis over the best check hybrid (BHM 9) for different characters of maize

Crosses	DT	DS	PH	EH	ASI	Y(t/ha)
1.Pinacle 20 × CML 429	-2.4	-4.9	-20.3**	-25.0*	-41.7*	-29.8**
2.Pinacle 20 × CML 425	-1.8	-3.8	-12.6*	-15.6	-33.3	-23.2**
3.BMZ 15 × CML 429	-5.3	-6.0	-29.0**	-35.0**	-16.7	-43.9**
4.BMZ 15 × CML 425	-8.8*	-8.8**	-35.1**	-38.9**	-8.3	-41.2**
5.BIL 79 × CML 429	4.1	0.5	-10.8*	-14.4	-50.0**	0.6
6.BIL 79 × CML 425	1.8	-1.1	-12.3*	-7.8	-41.7*	-12.1
7.Pinacle 17 × CML 429	3.5	3.3	-25.1**	-27.2**	0.0	-9.9
8.Pinacle 17 × CML 425	-0.6	-1.1	-23.1**	-28.9**	-8.3	-6.6
9.BMZ 55 × CML 429	-5.3	-5.5	-26.9**	-32.2**	-8.3	-33.7**
10.BMZ 55 × CML 425	-7.6*	-6.6	-36.2**	-43.9**	8.3	-39.0**
11.Pinacle 10 × CML 429	7.6*	3.8	-26.2**	-32.8**	-50.0**	-25.4**
12.Pinacle 10 × CML 425	0.6	-1.1	-16.7**	-7.2	-25.0	-17.6*
13.Pinacle 12 × CML 429	1.2	0.5	-13.6**	-18.9	-8.3	-27.0**
14.Pinacle 12 × CML 425	-4.7	-4.9	-10.3*	-3.3	-8.3	-21.9**
15.BMZ 68 × CML 429	-0.6	-2.7	-31.0**	-40.6**	-33.3	-26.6**
16.BMZ 68 × CML 425	-10.0**	-8.2*	-28.5**	-23.3*	16.7	-29.4**
17.CML 481 × CML 429	6.5	3.3	-19.7**	-5.6	-41.7*	-29.0**
18.CML 481 × CML 425	1.8	3.8	-14.4**	-10.6	33.3	-43.1**
19.CML 451 × CML 429	2.4	2.2	-17.4**	-21.7*	0.0	-14.3
20.CML 451 × CML 425	0.6	1.6	-24.9**	-31.78**	16.7	-42.9**
21.BMZ 25 × CML 429	1.2	-1.6	-22.8**	-28.9**	-41.7*	-24.6**
22.BMZ 25 × CML 425	1.2	-0.5	-27.9**	-12.2	-25.0	-32.3**
23. BMZ 56 x CML 429	-2.9	-5.5	-14.1**	-19.4*	-41.7*	-33.1**
24. BMZ 56 x CML 425	-1.2	1.1	-30.0**	-30.6**	33.3	-52.4**
25. BMZ 53 x CML 429	-2.4	-4.9	-27.2**	-38.3**	-41.7*	-26.2**

Crosses	DT	DS	PH	EH	ASI	Y(t/ha)
26. BMZ 53 x CML 425	-9.4**	-9.3**	-30.5**	-41.7**	-8.3	-39.2**
27. BMZ 4 x CML 429	-4.1	-6.6	-25.9**	-29.4**	-41.7*	-26.6**
28. BMZ 4 x CML 425	-6.5	-7.7*	-30.0**	-30.0**	-25.0	-47.7**
29. 900M 1 x CML 429	-1.2	-3.8	-25.9**	-27.8**	-41.7*	-24.1**
30. 900M 1 x CML 425	-0.6	-2.7	-22.6**	-16.1	-33.3	-37.9**
31. 900M 4 x CML 429	5.3	2.7	-9.2	-9.4	-33.3	-10.1
32. 900M 4 x CML 425	1.2	-0.5	-6.7	2.2	-25.0	-35.6**
33. CML 496 x CML 429	4.7	1.1	-8.5	-2.8	-50.0**	-17.2*
34. CML 496 x CML 425	2.9	0.0	-9.5	7.2	-41.7*	-28.9**
35. BIL 182 x CML 429	0.0	-3.3	-19.2**	-21.7*	-50.0**	-4.9
36. BIL 182 x CML 425	-4.1	-6.0	-26.2**	-23.9*	-33.3	-14.9*
37. Pinacle 3 x CML 429	-2.4	-4.9	-18.5**	-25.6**	-41.7*	-26.1**
38. Pinacle 3 x CML 425	-2.9	-4.9	-14.1**	-26.1**	-33.3	-42.0**
39. CML 487 x CML 429	-2.4	-3.3	-20.8**	-21.7*	-16.7	-33.4**
40. CML 487 x CML 425	-0.6	-1.6	-25.6**	-18.9	-16.7	-39.5**
41. 900M 10 x CML 429	1.8	0.5	-13.8**	-10.0	-16.7	-32.5**
42. 900M 10 x CML 425	-1.8	-1.6	-16.4**	-18.9	0.0	-40.0**
43. E 34 x CML 429	4.7	-0.5	-14.4**	-11.1	-75.0**	-16.6
44.E 34 x CML 425	-1.8	-3.8	-13.8**	-12.2	-33.3	-27.4**

* Significant at 5% level, ** Significant at 1% level

DT=Days to Tassel, DS=Days to Silk, PH=Plant Height, EH= Ear Height, ASI= Anthesis silking interval, Y=Yield

Days to pollen shedding and silking determine the maturity of the hybrid. For heterosis Days to tasseling and silking ranged from -10.0 to 7.6 % and -9.3 to 3.8% respectively. Negative heterosis is desirable for these two characters. Considering commercial hybrid BHM9 as a check four crosses BMZ 15 × CML 425, BMZ 55 × CML 425, BMZ 68 × CML 425, BMZ 53 x CML 425 showed significantl and negative heterosis for days to pollen shedding. Maximum negative heterosis was observed in the cross BMZ 68 × CML 425 for this trait. For days to silking three crosses BMZ 15 × CML 425, BMZ 68 × CML 425, BMZ 53 x CML 425 exhibited significantly and negative heterosis and highest negative heterosis was observed in the cross of BMZ 53 x CML 425.

Negative heterosis is desirable for plant height and ear height which helps for developing short statured plant leading tolerant to lodging. Heterosis for different crosses ranged from -36.2 to -6.7 % and -43.9 to 2.2%, respectively, for plant and ear height. Significant and negative heterosis for both these traits were reported by Uddin et al. (2006), Alam et al. (2008) and Amiruzzaman (2010).

In case of grain yield, the percent of standard heterosis varied from -52.6% to 0.6%. Most of the crosses showed significant and negative heterosis except BIL 79 × CML 429 which showed positive value.

Conclusion

Good general combining ability effects for yield and important yield contributing characters were noticed in the lines *viz.* BMZ 55, BMZ 53, BMZ 4 (earliness), BMZ 68, BMZ 15, BMZ 53, BMZ 55 (dwarf character) and, BIL 79, BIL 182 and Pinacle 17 (higher yield). These parents could result in the production of superior single crosses. Four crosses BMZ 15 × CML 425, BMZ 55 × CML 425, BMZ 68 × CML 425, BMZ 53 x CML 425 showed significant and negative heterosis for days to pollen shedding. For days to silking three crosses BMZ 15 × CML 425, BMZ 68 × CML 425, BMZ 53 x CML 425 exhibited significant and negative heterosis. In case of grain yield most of the crosses showed significant and negative heterosis except BIL 79 × CML 429 which showed positive value (0.6%), almost similar to the check variety. Hybrid BIL 182 x CML 429 and BIL 79 x CML 429 could be advanced for commercial hybrid development after verifying the performances over locations.

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