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Combining ability studies for yield and yield components in maize (*Zea mays* L.)

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Abstract
In the present investigation 55 F_1 maize hybrids derived by crossing eleven inbreds in half diallel fashion were evaluated to assess the nature of gene action and to estimate *gca* effects of inbreds and *sca* effects of hybrids for yield and yield components. The results revealed that the magnitude of *sca* variances ($\sigma^2 sca$) were higher than *gca* variances ($\sigma^2 gca$) for all the characters and also the ratio $\sigma^2 gca$ to $\sigma^2 sca$ was less than unity, which indicated the predominance of non-additive gene action in control of these traits. Based on *gca* effects, the inbreds *viz.,* BML 7, CM 119, BML 2 and BML 51were identified as the good general combiners and based on *sca* effects, the hybrids *viz.,* BML 5 × CML 124 and BML 51 × BML 5 were identified as the best specific combiners for yield and yield components.

Keywords: maize, gene action, *gca* effects, *sca* effects

Introduction
Maize (*Zea mays* L.) is one of the most important cereal crops and ranks third in total production next to rice and wheat. The demand for maize cultivation is increasing day by day in our country due to its high yield potential, versatile uses, almost year round growth ability and higher per acre yield than the other cereals. Hence, keeping in mind the current and future demands of maize, there is an immediate need to increase the production and productivity of maize in different niches. Though, many synthetics and composites have contributed to maize production in India in initial breeding programmes, currently single cross hybrids are playing a vital role due to their high yielding potential. There is a continuous need to develop new hybrids which should exceed the existing hybrids in yield. A suitable breeding methodology and identification of superior inbred lines are the most important pre-requisites for the development of high yielding hybrids. Combining ability analysis helps in the evaluation of inbreds in terms of their genetic value and in the selection of suitable parents for hybridization. It also helps in the identification of superior hybrid combinations which may be utilized for commercial exploitation of heterosis and also reveals the nature of gene action involved in the expression of characters and there by helps in formulating breeding methodology to be used for improvement of yield (Pal and Prodhan, 1994) [13]. Hence the present investigation was carried out to assess the nature of gene action for yield and yield components and to estimate *gca* effects of inbreds and *sca* effects of hybrids for yield and yield components.

Material and Methods
The experimental material for this study comprised of 55 F_1s derived by crossing in eleven inbreds (BML 51, BML 5, CM 105, BML 2, BML 6, BML 7, BML 15, BML 14, CM 118, CM 119 and CML 124) in half diallel fashion. The fifty five F_1s were evaluated using randomized block design with three replications during *rabi*, 2015-16 at Sri Venkateswara Agricultural College Farm, Tirupati, Andhra Pradesh. The plot size for each entry was single row of five meter length, with a spacing of 75 cm and 20 cm between row to row and plant to plant, respectively. The crop was raised as per the recommended cultural practices. The observations for seventeen yield and yield component traits *viz.,* days to 50 per cent tasseling, days to 50 per cent silking, anthesis-silking interval, days to maturity, SPAD chlorophyll meter reading (SCMR), specific leaf area, relative water content, leaf area index, plant height, tassel length, ear length, ear girth, number of kernel rows per ear, number of kernels per ear row, 100 kernel weight, protein content and kernel yield per plant were recorded on five randomly tagged competitive plants in each genotype in each replication. The mean of these five plants were used in the statistical analysis. However, for days to 50% tasseling, days to 50% silking, anthesis-silking interval and days to maturity the observations were recorded on plot basis. Combining ability analysis was done as per the procedure of Model I and Method IV of Griffing (1956) [6].

Results and Discussion

Analysis of variance for combining ability revealed that mean squares due to *gca* and *sca* were highly significant for all the characters under study, indicating the importance of both additive and non-additive gene action in the inheritance of the characters. Further, the magnitude of *sca* variances (σ^2*sca*) were higher than *gca* variances (σ^2*gca*) for all the characters and also the ratio of σ^2*gca* to σ^2*sca* was less than unity, which indicated the preponderance of non additive gene action in control of these traits (Table 1). Hence, it could be suggested that heterosis breeding can profitably used for exploitation of hybrid vigour in maize on commercial scale.Similarly, predominance of non additive gene action in the inheritance of yield and yield components in maize were reported by Debnath and Sarkar (1990) [3], Zelleke (2000) [17], Kanagarasu *et al*. (2010) [7], Pavan and Wali (2017) [14] and Murtadha *et al*. (2018) [11].

Table 1: ANOVA for combining ability and estimates of genetic components for yield and yield components in maize

		Mean squares			Genetic components		
S. No.	**Character**	**Due to *gca* (df = 10)**	**Due to *sca* (df = 44)**	**Error (df = 108)**	**σ^2 *gca***	**σ^2 *sca***	**σ^2 *gca* /σ^2 *sca***
1	Days to 50% tasseling	12.83**	5.96**	0.35	1.39	5.61	0.25
2	Days to 50% silking	13.10**	5.59**	0.54	1.40	5.06	0.28
3	Anthesis silking interval	0.86**	0.44**	0.17	0.08	0.27	0.29
4	Days to maturity	13.64**	6.63**	0.28	1.49	6.35	0.23
5	SPAD Chlorophyll Meter Reading	71.63**	17.77**	4.26	7.49	13.51	0.55
6	Specific leaf area (cm^2 g^{-1})	551.41**	156.65**	37.54	57.10	119.10	0.48
7	Relative water content (%)	20.55**	10.69**	3.10	1.94	7.59	0.26
8	Leaf area index	0.55**	0.39**	0.02	0.06	0.38	0.16
9	Plant height (cm)	1076.04**	358.46**	43.25	114.75	315.22	0.36
10	Tassel length (cm)	35.72**	9.39**	0.79	3.88	8.61	0.45
11	Ear length (cm)	3.16**	1.47**	0.47	0.30	1.00	0.30
12	Ear girth (cm)	1.93**	0.83**	0.23	0.19	0.60	0.31
13	No. of kernel rows/ear	4.38**	0.97**	0.20	0.46	0.77	0.60
14	No. of kernels/ear row	25.35**	9.92**	1.26	2.68	8.66	0.31
15	100 kernel weight (g)	15.16**	9.53**	1.46	1.52	8.07	0.19
16	Protein content (%)	0.99**	0.77**	0.08	0.10	0.69	0.15
17	Kernel yield per plant (g)	555.32**	184.85**	13.36	60.22	171.49	0.35

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

gca – general combining ability*; sca* – specific combining ability; **σ^2** *gca* – variance due to *gca ;* **σ^2** *sca* – variance due to *sca*.

General combining ability (GCA) effects

The general combining effects (*gca*) are of direct utility to decide the next phase of breeding programme since the general view is that, better general combining inbreds may yield better hybrid combination and can be directly utilized in development of synthetics as short term approach. The *gca* effects reflect performance of parents in combination with all other parents, so the parents with highest *gca* effects should have greater impact on the trait improvement. Dhillon (1975) [5] opined that combining ability provides useful information on the choice of parents in terms of expected performance of the hybrids and progenies.

The overall estimates of *gca* effects revealed that none of the parents were found to be good combiner for all the traits (Table 2). But most of the parents exhibited good *gca* effects for several characters. For kernel yield per plant, four out of eleven parents *viz.,* BML 7, CM 119, BML 2 and BML 51 were identified as good general combiners. In addition to kernel yield the inbred BML 7 exhibited good *gca* effects for eight traits *viz.*, ear length, ear girth, number of kernel rows per ear, number of kernels per ear row, 100 kernel weight, leaf area index, plant height and tassel length. Similarly the inbred CM 119 for eight traits *viz.*, ear girth, number of kernel rows per ear, 100 kernel weight, days to 50% tasseling, days to 50% silking, SCMR, leaf area index and tassel length, likewise the inbred BML 2 for seven traits *viz.*, number of kernels per ear row, anthesis-silking interval, days to maturity, SCMR, specific leaf area, relative water content, leaf area index and the inbred BML 51 for eight traits *viz.*, days to 50% tasseling, days to 50% silking, anthesis-silking interval, days to maturity, SCMR, relative water content, 100 kernel weight and protein content exhibited good *gca* effects. Hence, these inbreds *viz.*, BML 7, CM 119, BML 2 and BML 51 were regarded as good general combiners for most of the yield and yield component traits and could be well utilized in hybrid breeding programmes for development of superior hybrids. Similarly, Wali *et al*. (2010) [16], Badawy (2012) [1], Naik *et al*. (2014) [12], Khan and Dubey (2015) [8], Matin *et al*. (2016) [10] and Murtadha *et al*. (2018) [11] also identified good general combiners for yield and yield components in maize.

The inbreds BML 6, BML 51 and BML 14 were found to have negative *gca* effects for days to 50% tasseling, days to 50% silking and days to maturity indicating their usefulness for bringing out earliness in cross combinations. Similarly, Desai and Singh (2001) [4], Kanagarasu *et al*. (2010) [7] and Pavan and Wali (2017) [14] reported good general combiners for maturity traits. The inbreds BML 2 and CML 124 were the good general combiners for physiological traits *viz.*, SCMR, specific leaf area (SLA), relative water content (RWC) and leaf area index and could be effectively used for breeding superior genotypes for drought tolerance since SCMR, SLA and RWC are the drought parameters. Similarly, Desai and Singh (2001) [4] and Vinodhana and Ganesan (2017) [15] for relative water content; Manasa *et al.* (2014) [9] for SCMR and SLA, identified good general combiners.

Table 2: Estimates of general combining ability *(gca)* effects of eleven parents for yield and yield components in maize

S. No.	Character	BML 51	BML 5	CM 105	BML 2	BML 6	BML 7	BML 15	BML 14	CM 118	CM 119	CML 124	S.E (g_i)
1	Days to 50% tasseling	-0.91**	2.46**	-0.14	-0.14	-1.73**	0.42*	1.35**	-0.88**	-0.62**	-0.69**	0.87**	0.19
2	Days to 50% silking	-1.36**	2.49**	-0.62**	-0.40	-1.40**	0.90**	1.30**	-0.70**	-0.48*	-0.48*	0.75**	0.23
3	Anthesis silking interval	-0.45**	0.03	-0.49**	-0.27*	0.33*	0.48**	-0.04	0.18	0.14	0.22	-0.12	0.13
4	Days to maturity	-0.75**	-0.53**	-0.08	-0.71**	-1.08**	2.92**	-1.23**	-0.75**	0.51**	0.47**	1.25**	0.17
5	SPAD Chlorophyll Meter Reading	3.06**	-6.67**	-2.74**	2.25**	1.35*	-0.81	-1.27	0.63	0.13	1.53*	2.53**	0.67
6	Specific leaf area (cm^2 g^{-1})	16.29**	-1.24	-1.05	-6.14**	10.42**	4.95*	-1.73	7.05**	2.72	8.18**	-6.86**	1.95
7	Relative water content (%)	1.33*	-3.03**	1.54**	1.39*	-0.97	-0.24	2.03**	-0.52	-1.23*	-0.73	0.43	0.56
8	Leaf area index	-0.24**	-0.41**	-0.28**	0.25**	0.08	0.38**	-0.03	0.06	-0.17**	0.19**	0.17**	0.04
9	Plant height (cm)	1.46	-4.57*	4.95*	3.27	13.08**	19.04**	10.56**	1.30	-22.12**	0.31	-1.12	2.09
10	Tassel length (cm)	-2.23**	-2.72**	0.02	-0.18	-0.69*	3.88**	-0.83**	2.43**	-0.93**	1.94**	-0.69*	0.28
11	Ear length (cm)	0.35	0.37	-0.03	0.04	-0.45*	1.12**	-0.17	0.30	-1.27**	-0.24	0.01	0.22
12	Ear girth (cm)	-0.04	-0.81**	0.17	-0.11	0.24	0.92**	-0.48**	0.02	-0.39*	0.40**	0.06	0.15
13	No. of kernel rows/ear	-0.19	-1.29**	-0.09	-0.52**	0.60**	0.75**	-0.94**	0.12	0.81**	0.65**	0.09	0.14
14	No. of kernels/ear row	-1.73**	-1.42**	1.44**	1.03**	-0.12	2.63**	1.34**	-0.81*	-3.19**	0.16	0.66	0.36
15	100 kernel weight (g)	1.46**	-1.24**	-2.11**	-0.97*	0.55	1.57**	1.02**	0.75	-1.65**	0.82*	-0.20	0.38
16	Protein content (%)	0.24**	0.61**	-0.52**	-0.01	-0.10	-0.01	0.25**	0.19*	-0.52**	0.10	-0.11	0.09
17	Kernel yield per plant (g)	2.57*	-13.50**	1.88	2.75*	-4.66**	17.38**	-2.06	0.45	-8.76**	3.45**	0.50	1.16

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

Specific combining ability (SCA) effects

Based on *sca* effects, none of the crosses were found to have a good specific combination for all the traits studied (Table 3). The top five hybrids exhibiting high *sca* effects for yield and yield component traits are presented in Table 4. For kernel yield per plant, the hybrids *viz.*, BML 5 × CM 118, BML 5 × CML 124, BML 5 × BML 7, CM 105 × BML 7 and BML 7 × BML 15 recorded highly significant *sca* effects and regarded as the promising hybrids for improvement of kernel yield.

However, the hybrids *viz.*, BML 5 × CML 124, BML 51 × BML 5, BML 6 × BML 7 and BML 7 × BML 14 were found to be the best specific cross combinations for yield and yield components. The hybrid BML 5 × CML 124 exhibited significant *sca* effects in desired direction for 12 traits *viz.*, kernel yield per plant, ear length, ear girth, number of kernels per ear row, 100 kernel weight, protein content, plant height, tassel length, days to 50% tasseling, days to 50% silking, days to maturity and leaf area index. Similarly the hybrid BML 51 × BML 5 showed significant *sca* effects in desired direction for 11 traits *viz.*, kernel yield per plant, ear girth, number of kernels per ear row, 100 kernel weight, plant height, days to 50 % tasseling, days to 50% silking, days to maturity, SCMR, relative water content and leaf area index. Likewise the hybrid BML 6 × BML 7 for eight traits *viz.*, for kernel yield per plant, number of kernels per ear row, protein content, plant height, tassel length, days to 50% tasseling, days to maturity and SCMR and the hybrid BML 7 × BML 14 for eight traits *viz.*, ear girth, number of kernel rows per ear, 100 kernel weight and protein content, days to 50% tasseling, days to 50% silking, days to maturity and SCMR exhibited good *sca* effects in desired direction. Hence these hybrids could be exploited to isolate transgressive segregants and superior genotypes with respective traits could be obtained in subsequent generations. Similarly, Wali *et al*. (2010), Badawy (2012) [1], Naik *et al*. (2014) [12], Khan and Dubey (2015) [8], Matin *et al*. (2016) [10] and Murtadha *et al*. (2018) [11] also reported specific combiners for yield and yield components in maize.

Considering maturity traits the hybrids *viz.*, BML 51 × BML 5, BML 5 × CML 124 and BML 7 × CM 118 were found to have negative *sca* effects for days to 50% tasseling, days to 50% silking and days to maturity besides having positive *sca* effects for kernel yield, indicating their usefulness in hybrid breeding programmes to develop short duration hybrids with high yield. For drought tolerant characters *viz.*, SCMR, SLA and RWC the hybrids *viz.*, BML 51 × BML 5, CM 105 × BML 7 and BML 15 × CM 118 exhibited good *sca* effects besides having good *sca* effects for kernel yield. Hence, these hybrids could be suggested for use in hybrid breeding programme for development of drought tolerant hybrids with high yield.

In the present study the best specific combiners were the result of good × good, good × poor and poor × poor general combiners. The interaction between positive and positive alleles in crosses involving good × good combiners which can be fixed in subsequent generations. The superiority of crosses involving good × poor combiners as parents could be explained on the basis of interaction between positive alleles from good combiners and negative alleles from the poor combiners as parents. The high yield of such crosses would be non-fixable and thus could be exploited for heterosis breeding. The superior cross combinations involving poor × poor general combiners could result from over dominance. Therefore, one can afford to include some poor general combiners also along with good combiners in breeding programmes where hybridization is involved. These results were in conformity with the earlier reports of Dar *et al*. (2007), Khan and Dubey (2015) [8] and Murtadha *et al*. (2018) [11].

Table 3: Estimates of specific combining ability (*sca*) effects of 55 hybrids for yield and yield components in maize

S. No.	Hybrid	Days to 50% tasseling	Days to 50% silking	Anthesis silking interval	Days to maturity	SCMR	Specific leaf area	Relative water content	Leaf area index
1	BML 51 × BML 5	-2.60**	-2.39**	0.22	-1.83**	9.38**	2.73	5.13**	0.85**
2	BML 51 × CM 105	-2.01**	-1.61*	0.40	-0.61	1.39	1.07	-5.74**	0.35**
3	BML 51 × BML 2	1.66**	1.17	-0.49	2.36**	1.37	-6.33	0.48	-0.36**
4	BML 51 × BML 6	-1.08*	-1.50*	-0.42	1.39**	-0.17	5.67	1.98	0.04
5	BML 51 × BML 7	1.44**	1.87**	0.44	-1.61**	-3.37	8.48	-3.55*	0.59**
6	BML 51 × BML 15	-0.49	-0.53	-0.04	2.54**	2.18	-0.35	-2.58	-0.33**
7	BML 51 × BML 14	2.07**	1.80**	-0.27	2.06**	-0.72	16.17**	0.40	-0.11

8	BML 51 × CM 118	-1.19*	-1.09	0.10	-0.20	-0.38	-2.71	1.07	0.13
9	BML 51 × CM 119	0.55	0.58	0.03	-4.16**	-3.18	8.53	5.77**	-0.58**
10	BML 51 × CML 124	1.66**	1.69**	0.03	0.06	-6.48**	-0.93	-2.95	-0.59**
11	BML 5 × CM 105	-2.7**	-2.46**	0.25	-1.50**	5.88**	-1.27	4.07*	1.03**
12	BML 5 × BML 2	0.96	0.65	-0.30	1.13*	-1.01	-13.17*	-5.45**	0.13
13	BML 5 × BML 6	-1.12*	-0.35	0.77*	-2.50**	-1.37	9.23	-4.88**	-0.38**
14	BML 5 × BML 7	2.07**	1.02	-1.04**	0.50	-5.35**	-6.67	-0.48	-0.16
15	BML 5 × BML 15	-0.86	-1.39*	-0.53	-1.35**	-0.63	10.65	5.76**	0.05
16	BML 5 × BML 14	-0.64	-0.05	0.59	-3.16**	-5.43**	22.86**	1.18	-0.68**
17	BML 5 × CM 118	9.10**	9.39**	0.29	9.58**	10.03**	-0.52	-2.45	-0.90**
18	BML 5 × CM 119	-2.82**	-2.61**	0.22	0.28	5.74**	-13.33*	-3.62*	-1.12**
19	BML 5 × CML 124	-1.38*	-1.83**	-0.45	-1.16*	2.81	-10.50	0.74	1.18**
20	CM 105 × BML 2	0.88	0.76	-0.12	1.36**	-0.37	2.94	0.39	-0.43**
21	CM 105 × BML 6	-0.19	-0.57	-0.38	0.39	-3.13	14.53**	2.21	0.21
22	CM 105 × BML 7	4.99**	4.13**	-0.86*	1.39**	-5.51**	8.26	-2.50	-0.82**
23	CM 105 × BML 15	0.73	0.73	-0.01	-0.46	-8.59**	-3.29	-6.57**	0.28*
24	CM 105 × BML 14	-0.71	-0.61	0.10	0.39	4.68*	6.33	3.86*	-0.38**
25	CM 105 × CM 118	1.70**	2.50**	0.81*	0.80	1.38	-2.89	0.91	-0.26*
26	CM 105 × CM 119	0.10	-0.50	-0.60	-0.16	-0.18	5.08	2.12	0.06
27	CM 105 × CML 124	-2.79**	-2.39**	0.40	-1.61**	4.45*	-1.70	1.26	-0.03
28	BML 2 × BML 6	0.14	-0.79	-0.93*	2.36**	0.02	-12.56*	4.30**	-0.27*

S. No.	Hybrid	Days to 50% tasseling	Days to 50% silking	Anthesis silking interval	Days to maturity	SCMR	Specific leaf area	Relative water content	Leaf area index
29	BML 2 × BML 7	-0.01	0.24	0.25	-2.98**	1.98	-1.62	1.41	0.05
30	BML 2 × BML 15	0.73	1.17	0.44	-1.83**	-3.67*	1.66	0.37	-0.67**
31	BML 2 × BML 14	-1.04	0.50	1.55**	-1.64**	3.16	-12.56*	-1.63	1.15**
32	BML 2 × CM 118	-0.64	-1.39*	-0.75*	-1.24*	-1.77	32.17**	-0.73	0.47**
33	BML 2 × CM 119	-2.23**	-1.72**	0.51	0.47	-1.00	8.35	0.80	0.21
34	BML 2 × CML 124	-0.45	-0.61	-0.16	0.02	1.30	1.11	0.09	-0.28*
35	BML 6 × BML 7	-1.42**	-0.42	0.99**	-1.61**	4.74*	16.47**	1.73	-0.30*
36	BML 6 × BML 15	1.66**	2.17**	0.51	0.21	-0.94	22.70**	-2.30	-0.53**
37	BML 6 × BML 14	-0.45	-0.16	0.29	0.73	0.33	21.29**	-3.48*	0.53**
38	BML 6 × CM 118	-3.04**	-4.05**	-1.01**	-4.87**	-2.10	17.21**	2.62	-0.04
39	BML 6 × CM 119	2.36**	2.28**	-0.08	-0.50	1.70	1.24	-3.22*	0.01
40	BML 6 × CML 124	3.14**	3.39**	0.25	4.39**	0.93	0.65	1.06	0.76**
41	BML 7 × BML 15	-4.49**	-4.13**	0.36	-0.46	3.25	17.75**	1.44	-0.32**
42	BML 7 × BML 14	-2.27**	-2.13**	0.14	-0.94*	5.19**	-5.49	1.75	-0.04
43	BML 7 × CM 118	-2.19**	-2.02**	0.18	-1.53**	2.49	3.96	2.68	0.04
44	BML 7 × CM 119	0.22	0.99	0.77*	3.50**	-4.64*	2.01	-4.14**	0.52**
45	BML 7 × CML 124	1.66**	0.43	-1.23**	3.73**	1.22	-10.22	1.67	0.44**
46	BML 15 × BML 14	1.14*	0.47	-0.67	3.21**	1.34	16.44**	0.98	0.82**
47	BML 15 × CM 118	1.22*	0.911	-0.30	0.62	4.11*	-12.48*	-1.21	0.42**
48	BML 15 × CM 119	1.29*	0.91	-0.38	0.99*	2.88	-11.41*	4.57**	0.24*
49	BML 15 × CML 124	-0.93	-0.31	0.62	-3.46**	0.08	-8.80	-0.46	0.03
50	BML 14 × CM 118	-1.56**	-2.09**	-0.53	-1.53**	0.71	1.46	1.13	-1.00**
51	BML 14 × CM 119	1.51**	1.24	-0.27	0.84	-5.02**	-1.12	-2.97	0.13
52	BML 14 × CML 124	1.96**	1.02	-0.93*	0.06	-4.26*	-0.16	-1.21	-0.41**
53	CM 118 × CM 119	-0.75	-0.98	-0.23	-0.42	4.68*	15.85**	-1.56	1.39**
54	CM 118 × CML 124	-2.64**	-1.20	1.44**	-1.20*	0.91	14.06*	-2.45	-0.25*
55	CM 119 × CML 124	-0.23	-0.20	0.03	-0.83	-0.96	16.49**	2.25	-0.86**
	S.E (S_{ij})	0.53	0.654	0.368	0.473	1.845	5.48	1.575	0.117
	S.E ($S_{ij} – S_{ik}$)	0.79	0.975	0.549	0.705	2.75	8.17	2.347	0.175
	S.E ($S_{ij} – S_{kl}$)	0.739	0.912	0.513	0.659	2.573	7.642	2.196	0.163

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

S. No.	Hybrid	Plant height	Tassel length	Ear length	Ear girth	No. of kernel rows per ear	No. of kernels per ear row	100 Kernel weight	Protein content	Kernel yield per plant
1	BML 51 × BML 5	12.11*	1.11	0.64	0.84*	0.52	3.16**	2.19*	0.38	18.47**
2	BML 51 × CM 105	-18.48**	1.50	1.18	0.56	0.80*	3.37**	0.97	-0.15	7.13*
3	BML 51 × BML 2	-14.07*	0.83	-0.70	-0.67	-0.51	-0.15	-3.73**	1.42**	-8.89**
4	BML 51 × BML 6	21.82**	1.34	1.04	0.39	0.24	2.66**	2.36*	0.03	14.23**
5	BML 51 × BML 7	0.57	-3.83**	0.34	-0.36	-0.31	-3.28**	-0.62	-0.61*	14.29**
6	BML 51 × BML 15	22.68**	-1.05	-2.00**	-0.59	0.04	-3.40**	2.01	-0.83**	13.61**
7	BML 51 × BML 14	2.77	-3.58**	-0.35	0.49	0.38	-0.38	-2.68*	-0.96**	9.40**
8	BML 51 × CM 118	5.39	3.98**	0.03	-0.23	-0.11	2.54*	-0.31	0.87**	-0.52
9	BML 51 × CM 119	15.83**	1.17	1.56*	0.32	-0.34	-0.88	3.30**	0.49	-0.56
10	BML 51 × CML 124	-3.27	-1.46	-1.75**	-0.74	-0.71	-3.65**	-3.49**	-0.64*	11.35**

S. No.	Hybrid	Plant height	Tassel length	Ear length	Ear girth	No. of kernel rows per ear	No. of kernels per ear row	100 Kernel weight	Protein content	Kernel yield per plant
11	BML 5 × CM 105	11.08	-0.01	-0.41	0.36	0.56	-0.08	0.95	0.70**	5.70
12	BML 5 × BML 2	-6.57	-1.22	-1.47*	0.62	1.45**	-1.39	1.04	-1.24**	-0.88
13	BML 5 × BML 6	6.05	-0.31	-0.81	0.29	0.27	-0.05	-3.46**	0.22	-2.46
14	BML 5 × BML 7	15.00*	-0.01	-2.95**	-1.50**	-0.02	-4.50**	-1.07	-1.37**	23.53**
15	BML 5 × BML 15	8.95	0.24	0.97	0.46	-0.19	3.36**	0.97	-0.08	-1.04
16	BML 5 × BML 14	0.80	2.714**	1.31*	0.51	0.08	1.18	-1.11	1.13**	10.92**
17	BML 5 × CM 118	-32.91	-6.80**	0.78	-3.46**	-3.14**	-7.77**	-6.63**	-1.42**	31.29**
18	BML 5 × CM 119	-6.94	1.26	-0.23	0.78	-0.18	1.08	4.32**	0.40	18.77**
19	BML 5 × CML 124	22.42**	3.03**	2.17**	1.11*	0.65	5.51**	2.81*	1.28**	27.18**
20	CM 105 × BML 2	-11.23	-4.43**	-1.59*	-0.80	-0.88*	-0.72	-0.94	-0.22	-0.14
21	CM 105 × BML 6	-9.54	0.15	0.71	-0.59	-0.39	4.23**	4.35**	-0.34	15.26**
22	CM 105 × BML 7	31.59**	-4.22**	-1.81**	-0.89*	-0.81*	-5.65**	-2.75*	-0.26	22.68**
23	CM 105 × BML 15	27.71**	-5.83**	-1.02	-0.24	-0.32	-3.10**	-4.07**	-0.34	13.09**
24	CM 105 × BML 14	-3.12	3.44**	0.12	-0.59	-0.05	0.65	-0.75	-0.17	8.24*
25	CM 105 × CM 118	38.70**	2.33**	2.30**	1.25**	-1.27**	4.50**	3.23**	0.24	10.00**
26	CM 105 × CM 119	24.74**	4.12**	0.61	1.14**	0.10	-3.32**	2.98**	0.23	-2.97
27	CM 105 × CML 124	27.16**	2.95**	-0.08	-0.21	2.26**	0.12	-3.98**	0.33	-7.46*
28	BML 2 × BML 6	-7.30	0.48	0.52	0.43	0.03	-0.75	-3.00**	0.53*	0.41
29	BML 2 × BML 7	16.49**	0.84	1.79**	-0.48	0.41	0.7	-1.36	-0.51*	4.7
30	BML 2 × BML 15	0.07	0.63	0.30	-0.64	-0.16	-1.88	-0.34	0.73**	15.96**
31	BML 2 × BML 14	0.69	-1.77*	0.25	0.37	1.18**	0.54	2.88**	-0.37	8.04*
32	BML 2 × CM 118	5.58	1.92*	0.06	0.63	0.35	1.12	1.58	0.90**	5.39
33	BML 2 × CM 119	21.82**	2.58**	0.49	0.34	-0.28	4.14**	3.39**	-1.11**	9.09**
34	BML 2 × CML 124	-5.49	0.14	0.35	0.21	-1.59**	-1.6	0.48	-0.13	-1.75
35	BML 6 × BML 7	22.04**	4.22**	0.57	0.19	-0.71	3.98**	0.63	0.51*	17.21**
36	BML 6 × BML 15	12.05*	-1.33	0.18	-0.25	-0.08	-3.07**	-1.75	0.55*	-9.03**
37	BML 6 × BML 14	10.64	2.14**	-1.00	-0.28	-0.08	-4.52**	-1.52	-0.21	-16.32**
38	BML 6 × CM 118	10.80	0.83	-0.15	0.48	0.30	-0.74	2.11	-0.71**	-3.85
39	BML 6 × CM 119	19.37**	-2.11**	-1.50*	-0.43	0.20	-2.02*	-2.84**	0.75**	20.46**
40	BML 6 × CML 124	47.20**	-5.41**	0.45	-0.23	0.23	0.28	3.12**	-1.33**	5.01
41	BML 7 × BML 15	-1.00	4.97**	1.03	0.67	0.44	2.68**	-1.53	-0.74**	22.35**
42	BML 7 × BML 14	-3.67	-1.36	0.31	1.26**	0.84*	0.54	5.25**	1.69**	5.95
43	BML 7 × CM 118	-9.05	0.40	-0.46	1.70**	0.55	0.92	-0.09	0.26	10.54**
44	BML 7 × CM 119	20.32**	0.59	1.79**	-0.58	1.12**	2.46*	-1.76	1.47**	3.93
45	BML 7 × CML 124	0.88	-1.58*	-0.62	-0.01	-1.52**	2.66**	3.30**	-0.45	-4.18
46	BML 15 × BML 14	13.07*	2.76**	0.46	0.86*	0.13	0.92	3.92**	1.16**	17.20**
47	BML 15 × CM 118	2.56	1.18	0.47	-0.16	0.24	4.20**	1.57	-0.04	13.87**
48	BML 15 × CM 119	-5.54	-3.49**	-0.67	-0.24	-0.26	1.75	-3.74**	-0.86**	2.75
49	BML 15 × CML 124	20.23**	1.94*	0.27	0.15	0.17	-1.45	2.94**	0.45	-3.43
50	BML 14 × CM 118	-10.65	-5.35**	-0.31	-0.68	0.65	0.02	-3.46**	-1.19**	-6.62*
51	BML 14 × CM 119	23.15**	-1.89*	-0.99	-0.93*	-1.32**	-1.2	-2.17*	-0.83**	-9.99**
52	BML 14 × CML 124	12.62*	2.88**	0.21	-1.02*	-1.82**	2.24*	-0.36	-0.24	-4.98
53	CM 118 × CM 119	-5.39	0.87	-1.40*	-0.33	0.52	-1.35	1.66	-0.10	0.48
54	CM 118 × CML 124	-5.03	0.63	-1.33*	0.81	1.89**	-3.45**	0.33	1.18**	1.99
55	CM 119 × CML 124	22.32**	-3.11**	0.34	-0.07	0.45	-0.67	-5.14**	-0.44	-1.03
	S.E (S_{ij})	5.882	0.793	0.612	0.429	0.403	1.005	1.082	0.254	3.27
	S.E ($S_{ij} - S_{ik}$)	8.768	1.182	0.913	0.639	0.601	1.498	1.613	0.378	4.874
	S.E ($S_{ij} - S_{kl}$)	8.202	1.105	0.854	0.598	0.562	1.401	1.509	0.354	4.559

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

Table 4: Top five hybrids identified based on *sca* effects for yield and yield components in maize

S. No.	Character	Top five hybrids	S.No.	Character	Top five hybrids
1	Days to 50% tasseling	BML 7 × BML 15 BML 6 × CM 118 BML 5 × CM 119 CM 105 × CML 124 BML 5 × CM 105	10	Tassel length (cm)	BML 7 × BML 15 BML 6 × BML 7 CM 105 × CM 119 BML 51 × CM 118 CM 105 × BML 14
2	Days to 50% silking	BML 7 × BML 15 BML 6 × CM 118 BML 5 × CM 119 BML 5 × CM 105 BML 51 × BML 5	11	Ear length (cm)	CM 105 × CM 118 BML 5 × CML 124 BML 2 × BML 7 BML 7 × CM 119 BML 51 × CM 119
3	Anthesis silking interval	BML 7 × CML 124	12	Ear girth (cm)	BML 7 × CM 118

		BML 5 × BML 7 BML 6 × CM 118 BML 2 × BML 6 BML 14 × CML 124			BML 7 × BML 14 CM 105 × CM 118 CM 105 × CM 119 BML 5 × CML 124
4	Days to maturity	BML 6 × CM 118 BML 51 × CM 119 BML 15 × CML 124 BML 5 × BML 14 BML 2 × BML 7	13	No. of kernel rows/ear	CM 105 × CML 124 CM 118 × CML 124 BML 5 × BML 2 BML 2 × BML 14 BML 7 × CM 119
5	SPAD Chlorophyll Meter Reading	BML 5 × CM 118 BML 51 × BML 5 BML 5 × CM 105 BML 5 × CM 119 BML 7 × BML 14	14	No. of kernels/ear row	BML 5 × CML 124 CM 105 × CM 118 CM 105 × BML 6 BML 15 × CM 118 BML 2 × CM 119
6	Specific leaf area (cm^2 g^{-1})	BML 5 × CM 119 BML 5 × BML 2 BML 2 × BML 6 BML 2 × BML 14 BML 15 × CM 118	15	100 kernel weight (g)	BML 7 × BML 14 CM 105 × BML 6 BML 5 × CM 119 BML 15 × BML 14 BML 2 × CM 119
7	Relative water content (%)	BML 51 × CM 119 BML 5 × BML 15 BML 51 × BML 5 BML 15 × CM 119 BML 2 × BML 6	16	Protein content (%)	BML 7 × BML 14 BML 7 × CM 119 BML 51 × BML 2 BML 5 × CML 124 CM 118 × CML 124
8	Leaf area index	CM 118 × CM 119 BML 5 × CML 124 BML 2 × BML 14 BML 5 × CM 105 BML 51 × BML 5	17	Kernel yield per plant (g)	BML 5 × CM 118 BML 5 × CML 124 BML 5 × BML 7 CM 105 × BML 7 BML 7 × BML 15
9	Plant height (cm)	BML 6 × CML 124 CM 105 × CM 118 CM 105 × BML 7 CM 105 × BML 15 CM 105 × CML 124			

Conclusion

The combining ability analysis estimates in the present investigation revealed predominance of non-additive gene action in the inheritance of all the characters under study hence it could be suggested that heterosis breeding can profitably used for exploitation of hybrid vigour in maize on commercial scale. The inbred lines BML 7, CM 119, BML 2 and BML 51 were identified as best general combiners for yield and yield components and these inbreds could be used as parents in hybrid breeding programmes or for development of the synthetic varieties. Whereas the hybrids *viz.*, BML 5 × CML 124 and BML 51 × BML 5 were best specific cross combinations for yield and yield components. Hence, these crosses could be developed as commercial hybrids after testing their performance in multi-location and on farm trials over the years or further forwarded to advanced generation in order to isolate desirable transgressive segregants for utilization in breeding programmes for development of superior inbred lines.

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