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Genetic Studies in Maize (*Zea mays* L.) under Plains of Kashmir Valley

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ABSTRACT

The investigation was carried out to generate information on combining ability, gene action and heterosis. The experimental material comprised of 28 F[1]'s derived from crossing 8 maize inbred lines in a half diallel fashion. All the crosses along with parental lines and two checks (DHM-117 and PMH-10) were evaluated in a Randomized Complete Block Design (RCBD) with three replications. Data recorded for morphological, maturity, yield and yield attributing traits was subjected to analysis of variance (ANOVA) which revealed highly significant differences among the parents and their crosses, indicating that there is significant diversity among the parents and the crosses. Analysis of variance for combining ability revealed significant mean squares for GCA and SCA for all traits, indicating the presence of both additive and non-additive gene actions. Among the parental lines, BML-6 and UMI-1200 depicted desirable significant negative GCA effects for maturity. Similarly, LM-13 and UMI-1200 showed positive significant GCA effect for grain yield plant^{-1}. Estimates of SCA effects showed that among the crosses, CML-451 X BML-6 and LM-14 X UMI-1200 showed desirable and highly significant negative SCA effect for days to maturity. Cross combinations, CML-451 X LM-13 and BML-10 X V-405 showed desirable highly significant SCA effect for grain yield plant^{-1}. Besides, cross combinations CML-451 X LM-13, BML-10 X V-405 and BML-10 X UMI-1200 depicted more than 30 and 20% economic heterosis over standard checks, DHM-117 and PMH-10, respectively. The potential hybrids need to be evaluated further, over locations and years to have a realistic view of their performance. Also parental lines with significant negative GCA effects for maturity traits and significant positive GCA effects for yield attributing traits can

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be utilized in future crossing programs as potential parents for development of medium maturing and high yielding hybrids.

Keywords GCA, Genetic studies, Heterosis, Inbred lines, Maize.

INTRODUCTION

Maize (*Zea mays* L.) belongs to the grass family Poaceae, genus Zea and species *Zea mays*. It originated in Mexico. Maize is one of the most important cereal grain crop grown worldwide in a wide range of environments because of its better adaptability. The crop plays a major role in the global economy and trade as food, feed and an industrial crop. Maize has a high rate of photosynthetic activity because of its C_4 pathway, resulting in its enhanced grain yield and biomass production. It is cross-pollinated crop which contributed to its wide morphological variability and geographical adaptability (Majid *et al*. 2020 *et al*.). Globally, the production of maize is 1147.6 million tons (mt) cultivated on an area of 193.7 million hectares (mha) with productivity of 5.92 t ha^{-1} (FAO 2018). In India, maize is the third important food crop after rice and wheat grown on an area of 9.2 million hectares (mt) with annual production of 30.24 milliontons (mt) and productivity of 30.23 q ha^{-1} (FAO 2018). In Jammu and Kashmir, maize is grown on an area of 3.1 lac hectares with production of 498 thousand tons and average productivity of 17.82 q ha^{-1} (Anonymous 2018).

Maize demand will rise at global, national and regional level, in view of increasing demand in poultry and livestock. The need to meet such demands acts as the key contributor for interventions like maize hybrid technology and novel molecular tools and techniques in maize improvement which ultimately shall contribute to increasing productivity. Since the commencement of the All India Coordinated Maize Improvement Project (AICMIP) in 1957, maize improvement in India has gone through numerous phases and single cross hybrids have provided considerable rewards in terms of area, output and productivity in India as compared to others. The fundamental breeding strategy for exploitation of heterosis in maize has been to identify single crosses with high heterotic effects by analysing cross combinations of superior inbred lines with high vigour.

For a hybrid development program, information on the combining ability and heterotic pattern of germplasm is a key and critical aspect. The magnitude of genetic variability in the base population and superior inbred growth are almost entirely responsible for hybrid development. Combining ability plays a crucial role in the improvement of crops to analyze the inbred lines for their propensity to create potential hybrids. In order to attain this goal, breeders use different mating designs. The notable among them is diallel crossing technique (Jink 1954, Hayman 1954) which gives information on the inheritance pattern of gene action in early filial generations for hybrid development. This approach can be used for statistically differentiating progeny performance into components related to general combining ability (GCA) and specific combining ability (SCA). The present study was undertaken with a view to estimate general and specific combining ability of maize (*Zea mays* L.) inbred lines and crosses, respectively. This is to estimate the gene action and heterosis for various traits of maize (*Zea mays* L.) inbred lines.

MATERIALS AND METHODS

The experimental material consists of eight inter-institutional maize inbred lines which were crossed in all possible combinations, excluded reciprocals, in diallel mating fashion (half diallel fashion) suggested by Griffing (1956) to produce 28 cross combinations at Winter Nursery Centr, Rajendranagar, Hyderabad, during *rabi*, 2019-2020. Eight parents and 28 hybrids along with 2 checks were sown in Randomized Complete Block Design with 3 replications for evaluation program at Faculty of Agriculture, SKUAST-K, during *kharif*. 2020 (Tables 1 - 3). The material was sown in single rows as plots of 4m length. Plant to plant spacing was maintained at 20 cm and row to row distance at 75 cm. The observations were recorded on 5 randomly selected plants for plant height, ear height, cob lenght, cob diameter, number of cobs plant^{-1}, kernal rows cob^{-1}, number of kernals row^{-1}, grain yield plant^{-1}except for days to silking, tasseling, ASI and maturity which were recorded on plot basis.

Table 1. Parental lines used in the crossing program.

Sl.No.	Parents (Inbreds)	Source
1	CML-451	CIMMYT, Hyderabad
2	LM-13	PAU, Ludhiana
3	LM-14	PAU, Ludhiana
4	BML-6	PJTSAU, Hyderabad
5	BML-10	PJTSAU, Hyderabad
6	UMI-1200	TNAU, Coimbatore
7	V-405	VPKAS, Almora
8	IML-187	IIMR, Ludhiana

RESULTS AND DISCUSSION

The analysis of variance for experimental design is important as it is an indicator of the measure of amount of variability existing in the experimental material. ANOVA results of this study showed highly significant variations for all traits among treatments (genotypes) and between parents and their crosses, suggesting that the material selected was diverse and produced substantial genetic variation in the crosses (Table 4). The mean sum of squares due to treatments, parents and crosses exhibited major differences for all the characteristics except for anthesis silking interval. Darshan and Marker (2019) also revealed the significant differences among the parents and experimental hybrids for all characters except anthesis silking interval. Parents vs hybrids showed a highly significant mean sum of squares for most of the traits and thus implies presence of significant differences of average performance of hybrids from the parents for traits except for days to 50 % silking, days to 50 % tasseling, ASI, ear height, cob length, number of cobs plant^{-1} and kernal rows cob^{-1}.

Table 2. Cross combinations for evaluation.

Sl. No.	Cross combinations	Sl. No.	Cross combinations
1	CML-451 X LM-13	15	LM-14 X BML-10
2	CML-451 X LM-14	16	LM-14 X UMI1200
3	CML-451 X BML-6	17	LM-14 X V-405
4	CML-451 X BML-10	18	LM-14 X IML-187
5	CML-451 X UMI-1200	19	BML-6 X BML-10
6	CML-451 X V-405	20	BML-6 X UMI-1200
7	CML-451 X IML-187	21	BML-6 X V-405
8	LM-13 X LM-14	22	BML-6 X IML-187
9	LM-13 X BML-6	23	BML-10XUMI-1200
10	LM-13 X BML-10	24	BML-10 X V-405
11	LM-13 X UMI-1200	25	BML-10 X IML-187
12	LM-13 X V-405	26	UMI-1200 X V-405
13	LM-13 X IML-187	27	UMI-1200XIML-187
14	LM-14 X BML-6	28	V-405 X IML-187

Table 3. Checks for evaluation of heterosis.

Sl. No.	Name of the check	Source
1	Punjab Maize Hybrid-10 (PMH-10)	PAU, Ludhiana
2	Deccan Hybrid Maize-117 (DHM-117)	PJTSAU, Hyderabad

Analysis of variance for combining ability

Analysis of variance for combining ability revealed significant mean sum of squares (MSS) due to GCA and due to SCA for all the characters studied, which indicate the importance of both additive and non-additive gene action in the inheritance of these traits (Table 5). Similar results of significant GCA and SCA variances for all characters have been reported by Muraya *et al*. (2006), Zelleke (2000), Amiruzzaman *et al*. (2013) and El-Shamarka *et al*. (2015). MSS for GCA has higher magnitude than SCA for days to maturity, indicating prepondance of additive gene action for the trait, which are in line with the findings of Hoque *et al*.(2016) and Matin *et al*. (2017) who reported similar findings for days to 50 % tasseling, days to 50% silking and days to maturity,whereas SCA exhibited higher magnitude for all other traits, viz, days to 50% tasseling, days to 50% silking, plant height, cob length, number of cobs plant^{-1}, kernels rows cob^{-1}, kernels row^{-1}, cob diameter, grain yield plant^{-1}, indicating presence of non-additive gene action for these traits. Similar results were also reported by Mahto and Ganguli (2003), Satyanarayana *et al*. (1990), Debnath and Sarkar (1990), Dass *et al*. (1997), Singh and Gupta (2009), Amiruzzaman *et al*. (2013), Niyonzima *et al*. (2015), Aslam *et al*. (2017). For all traits, dominance variance ($\sigma^{\wedge 2}D$) values were observed much higher as compared to additive variance ($\sigma^{\wedge 2}A$) and therefore the additive to dominance variance ratio was observed to be less than unity. This revealed that non additive variance played a major role in the inheritance of all traits as compared to additive variance. Same findings were recorded by Yerva *et al*. (2016) where the addidtive to dominance variance ratio was lower than unity

Table 4. Analysis of variance for experimental design for 12 morphological, yield and yield attributing in maize (*Zea mays* L.).

Source of variation	Df	Days to 50% tasseling	Days to 50% silking	ASI	Days to maturity	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob diameter (cm)	Number of cobs $plant^{-1}$	Kernel rows cob^{-1}	Number of kernels row^{-1}	Grain yield $plant^{-1}$
Replications	2	2.98	1.03	0.13	8.08	135.35*	51.49	1.20	0.04	0.001	0.60	2.05	251.53
Treatments	35	37.98**	86.31**	0.69	65.16**	1825.90**	862.01	25.50**	1.77**	0.08**	4.56**	327.66**	6597.72**
Parents	7	36.45**	110.71**	0.48	31.89**	3379.65**	1045.10	29.29**	2.27**	0.07**	6.89**	500.89**	9894.73**
Hybrids	27	38.96**	82.94**	0.7	70.20**	1397.76**	583.71	25.34**	1.62**	0.08**	4.13**	291.78**	5833.94**
Parents vs hybrids	1	22.32	6.71	0.06	162.05**	2512.56**	898.5	3.33	2.30**	0.03	0.02	83.72**	4140.54**
Error	70	2.68	2.31	0.2	2.93	31.89	16.35	1.74	0.02	0.02	0.87	4.28	154.28
Total	107	14.23	29.77	0.47	23.38	620.68	381.0	9.50	0.59	0.04	2.07	110.02	2263.77

for all the traits. In this study, the predictability ratio ($2\sigma^{\wedge 2}g/2\sigma^{\wedge 2}g+\sigma^{\wedge 2}s$) was found to be less than unity for all the traits, indicating that the predictability of the performance of progeny based on GCA would be negligible. This indicates rather that progeny performance was based more on SCA which accounted for major genetic variability. Similar findings were reported earlier by Loesch (1972) Dhillon and Singh (1977) and Prasad *et al*. (1988).

General combining ability effects

The GCA estimates revealed that none of parent showed significant GCA effects in the desired direction for all the traits (Table 6). However, general combining estimates for day to 50% tasseling and days to 50% silking, indicated that among parents, viz., V-405 and IML-187 were having highly significant negative GCA effects for both traits. The lines BML-6 and BML-10 were classified as desirable parents for days to maturity as it exhibited highest negative and significant GCA effect for the trait. Presence of high GCA effects for maturity traits in maize were also reported by Vasal *et al*. (1993), Sedhom (1994) and Zelleke (2000). LM-14, UMI-1200 and IML-187 were considered as good general combiners for plant height and UMI-1200, V-405 and LM-13 as good general combiners for ear height as reflected by their significant negative but desirable GCA effects. Satyanarayana *et al*. (1990), Mahajan and k Khera (1991), San Vicente *et al*. (1998) and Zelleke (2000) also reported the presence of high gca effects for plant type traits in maize. Considering the yield traits like cob length and cob diameter, UMI-1200 and LM-14, respectively were good general combiners. BML-6 was considered as good general combiner for number of cobs $plant^{-1}$, kernel rows cob^{-1} and kernels row^{-1}. LM-13 and UMI-1200 were good general

Table 5. Analysis of variance for combining ability and estimation of components of genetic variation for 11 morphological, yield and yield attributing in maize (*Zea mays* L.). *, ** Significant at 5 and 1 % level.

Source of variation	Df	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob diameter (cm)	Cobs $plant^{-1}$	Kernal rows cob^{-1}	Kernals $row-^{1}$	Grain yield $plant^{-1}$ (g)
GCA	7	10.88**	20.69**	23.25**	221.90**	127.75**	1.53*	0.08**	0.02**	1.06**	20.76**	186.96**
SCA	28	13.03**	30.85**	21.34**	705.46**	327.24**	10.24**	0.71**	0.03**	1.63**	131.37**	2702.31**
Error	70	0.91	0.77	0.97	10.62	5.45	0.58	0.009	0.008	0.29	1.42	51.43
$\sigma^{\wedge 2}g$		0.99	1.99	2.22	21.12	12.22	0.09	0.008	0.001	0.07	1.93	13.55
$\sigma^{\wedge 2}s$		12.12	30.08	20.36	694.83	321.78	9.66	0.70	0.01	1.34	129.94	2650.88
$\sigma^{\wedge 2}A$		1.99	3.98	4.45	42.25	24.45	0.19	0.02	0.003	0.15	3.86	27.10
$\sigma^{\wedge 2}D$		12.12	30.08	20.36	694.83	321.78	9.66	0.70	0.02	1.34	129.94	2650.88
$\sigma^{\wedge 2}A/\sigma^{\wedge 2}D$		0.16	0.09	0.21	0.06	0.07	0.02	0.02	0.18	0.11	0.02	0.01
$2\sigma^{\wedge 2}g/2\sigma^{\wedge 2}g+\sigma^{\wedge 2}s$		0.14	0.11	0.17	0.05	0.07	0.01	0.02	0.15	0.10	0.02	0.01

Table 6. Estimation of general combining ability effects for morphological, maturity, yield and yield attributing traits in maize (*Zea mays* L.). *, ** Significant at 5 and 1 % level.

Parents	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob diameter (cm)	Cobs plant^{-1}	Kernal rows cob^{-1}	Kernals row^{-1}	Grain yield plant^{-1} (g)
CML-451	0.23	-0.17	-0.27	6.63**	2.42*	-0.11	-0.11**	-0.01	-0.15	-0.13	0.32
LM-13	0.23	-0.43	-0.37	0.35	-2.25*	0.36	-0.02	-0.06*	0.11	0.40	5.14*
LM-14	1.65**	2.69**	2.12*	-3.52**	0.47	-0.02	0.21**	0.01	0.30	-1.11*	2.81
BML-6	0.76*	0.49	-1.80**	5.02**	7.37**	-0.03	0.02	0.07*	0.56**	2.42**	4.53
BML-10	0.39	0.75*	0.55	-1.30	-0.71	-0.37	0.008	-0.05	-0.32	0.21	2.46
UMI1200	-0.53	0.16	-2.17**	-4.82**	-4.3**	0.75*	-0.04	0.05	-0.41*	0.15	5.17*
V-405	-1.33**	-1.88**	1.79**	3.60**	-1.83*	-0.43	-0.007	0.002	-0.14	-2.53**	4.43
IML-187	-1.40**	-1.61**	0.15	-5.96**	-1.17	-0.14	-0.04	-0.01	0.04	0.87*	4.82
SE(gi)	0.28	0.25	0.29	0.96	0.69	0.22	0.02	0.02	0.15	0.35	2.12
SE(gi-gj)	0.42	0.39	0.44	1.45	1.04	0.33	0.04	0.03	0.23	0.53	3.20

combiner for grain yield plant^{1} as reflected by their significant positive GCA effects. These can be used directly as parents for developing high yielding single cross hybrids. There are several evidences in the literature where GCA effect has been used to identify good combiners for grain yield plant^{-1} and its related traits. Beck *et al*. (1991), Vasal *et al*. (1993), Setiyono (1996), Sedhom (1994), Dass *et al*. (1997), Marker *et al*. (2002) and Majid *et al*. (2020b) have successfully used significant positive GCA effect to identify good combiners for grain yield plant^{-1} and its related traits.

Specific combining ability effects

The evaluation of the result with respect to specific combining ability effects of the 28 F_1's for various traits in this study, showed that none of the cross combination exhibited significant and desirable SCA effects for all the traits (Table 7). However, several cross combinations were observed to give highest desirable significant SCA effect and *per se* performance for each trait. The results indicated that crosses having significantly high SCA effects involved high, average and low general combiners as parents. For maturity traits like days taken to 50% tasseling, CML-451 x LM-13, LM-13 x UMI-1200, LM-14 x BML-6 and BML-6 x UMI-1200 showed significant negative SCA effect in desirable direction. Similarly for days to 50% silking the significant negative desirable SCA effects exhibited by CML-451 X LM-14, LM-13 X UMI-1200, LM-14 X BML-6, LM-14 X V-405 and BML-6 X UMI-1200. The desirable cross combinations for days to maturity were CML-451 X BML-6, LM-13 X UMI-1200, LM-14 X UMI-1200, BML-6 X IML-187 which showed negative and significant SCA effect for maturity traits and were regarded as good combiners for earliness, as the ones with positive significant values are generally regarded as poor combiners. For morphological traits the best cross combination exhibiting desirable significant SCA effect for plant height were LM-13 X UMI-1200, UMI-1200 X V-405 and V-405 X IML-187 and for ear height, LM-13 X BML-6, LM-14 X V-405 and UMI-1200 X V-405 as it reflected desirable significant negative SCA effects.Similar findings for high SCA effects for maturity traits, plant height and ear height in maize were reported by Sedhom (1994) and Zelleke (2000), Malik *et al*. (2004), Subramanian and Subbaraman (2006), Mahajan and Khehra (1991), San Vicente *et al*. (1998), Devi *et al*. (2007), Gissa *et al*. (2007), Moradi (2014).

For number of cobs plant^{-1}, none of the crosses showed the desirable positive SCA effect. Whereas, BML-6 X V-405 and UMI-1200 X IML-187showed undesirable negative and significant SCA effect.

For cob length, five cross combinations,LM-13 X UMI-1200,LM-13 X IML-187, LM-14 X IML-187, BML-10 X UMI-1200 and BML-10 X V-405, were found as good specific combiners as they depicted highest significant and desirable SCA effects. For cob diameter, crosses, CML-451 X LM-13, CML-451 X UMI-1200, LM-13 X LM-14, LM-13 X BML-10,

Table 7. Estimation of specific combining ability effects for morphological, maturity, yield and yield attributing traits in maize (*Zea mays* L.). *, ** Significant at 5 and 1 percent level.

Crosses	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob diameter (cm)	Cobs plant^{-1}	Kernal rows cob^{-1}	Kernals row^{-1}	Grain yield plant^{-1} (g)
CML-451 X LM-13	-2.64**	-1.81*	-1.76	17.90**	0.55	1.27	0.53**	0.03	0.08	7.75**	36.82**
CML-451 X LM-14	-1.07	-2.26**	3.06**	0.55	-0.13	0.96	0.49**	-0.01	0.02	2.79*	37.28**
CML-451 X BML-6	2.15*	1.93*	-8.00**	46.70**	40.29**	3.07**	0.14	-0.07	1.69**	8.59**	36.93**
CML-451 X BML-10	1.18	0.66	4.63*	2.80	-2.14	-0.65	0.29**	0.02	-1.24*	-1.12**	16.33**
CML-451 X UMI-1200	1.45	1.25	-1.96*	14.15**	3.94	-0.58	0.72**	-0.05	0.70	5.20**	25.39*
CML-451 X V-405	0.91	2.97**	3.40**	22.65*	18.41**	0.70	0.41**	-0.10	0.53	3.45**	13.90*
CML-451 X IML-187	1.98*	2.71**	5.03**	-1.43	1.64	-0.11	0.21*	0.01	0.22	8.48**	-4.80
LM-13 X LM-14	0.59	-0.01	1.83	2.22	7.64**	1.21	0.52**	-0.09	1.03*	1.73**	25.41**
LM-13 X BML-6	1.81*	2.52**	6.43**	1.81	-9.38**	1.46*	0.26**	-0.02	1.46**	6.59**	-6.03
LM-13 X BML-10	4.18*	3.58**	-0.26	5.84	5.83*	-2.46**	0.71**	0.10	1.79**	-4.42**	22.23**
LM-13 X UMI-1200	-2.54**	-3.15**	-4.20**	-12.63**	9.22**	4.83**	0.17	-0.07	0.41	8.83**	26.72**
LM-13 X V-405	4.25**	4.56**	1.83	16.73**	16.42**	0.26	0.26**	-0.01	-1.02*	7.21**	32.26**
LM-13 X IML-187	-1.01	-1.03	1.46	14.37**	11.86**	3.03**	0.66**	-0.10	1.45**	8.11**	40.52*
LM-14 X BML-6	-4.60**	-5.59**	3.26**	-0.67	2.95	2.78**	0.22*	-0.11	-0.02	6.34**	35.08*
LM-14 X sBML-10	2.42**	4.46**	2.23*	-2.57	3.04	1.62*	0.20*	-0.17*	0.10	5.31**	7.85
LM-14 X UMI-1200	1.69	9.38**	-5.03**	16.43**	12.70**	1.78*	-0.13	-0.09	0.45	9.25**	25.34**
LM-14 X V-405	-1.83*	-3.88**	-3.33**	4.81	-6.20**	-3.84**	0.49**	-0.03	0.71	-5.03**	9.59
LM-14 X IML-187	3.56**	2.17*	5.30**	36.28**	12.90**	3.32**	0.29**	-0.04	0.06	9.42**	6.08
BML-6 X BML-10	1.65	0.66	1.16	6.34*	-4.15	0.30	0.52**	-0.24*	0.54	5.84**	37.33**
BML-6 X UMI-1200	-3.74**	-3.74**	-0.43	20.32**	1.00	-0.83	0.48**	0.37*	-1.14*	2.78*	31.59**
BML-6 X V-405	-1.28	-1.35	7.26**	12.13**	5.13*	2.13**	0.34**	-0.29**	-0.77	7.49**	9.30
BML-6 X IML-187	0.78	2.37**	-3.43**	4.80	2.66	0.43	0.45**	-0.07	0.80	7.19**	31.83**
BML-10 X UMI-1200	5.28**	4.32**	6.53**	10.32**	15.25**	2.43**	0.53**	0.01	-0.54	9.19**	39.09*
BML-10 X V-405	3.41**	2.71**	0.90	20.69**	20.25	6.20**	0.05	-0.03	0.74	15.27**	47.94**
BML-10 X I ML-187	2.48**	2.77**	1.86*	6.53*	0.45	0.47	0.39**	-0.14	1.79**	1.86	-23.53**
UMI-1200 X V-405	4.68**	4.30**	2.63**	-1.69**	-22.68**	-3.26**	0.45**	0.02	0.86	-3.89**	-6.86

Table 7. Continued

Crosses	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob diameter (cm)	Cobs plant^{-1}	Kernal rows cob^{-1}	Kernals row^{-1}	Grain yield plant^{-1} (g)
UMI-1200 X IML-187	-1.91*	-1.29	-2.06*	37.78**	27.38**	1.94**	0.55**	-0.09**	1.24*	1.03	40.86**
V-405 X IML-187	0.21	1.08	1.30	-11.00**	2.44	1.67*	0.48**	0.09	-0.98	1.71	47.23**
SE (sij)	0.86	0.79	0.89	2.95	2.11	0.68	0.08	0.08	0.48	1.07	6.50
SE(sij-sjk)	1.28	1.17	1.32	4.37	3.13	1.01	0.13	0.11	0.71	1.59	9.62

LM-13 X IML-187, UMI-1200 X IML-187 showed highest significant positive SCA effects and also revealed high to average *per se* performance.

For other yield component traits, the crosses like, CML-451 X BML-6, LM-13 X BML-6, LM-13 X BML-10, LM-13 X IML-187 and BML-10 X IML-187exhibited significant and desirable SCA effects for kernel rows cob^{-1} and for kernels row^{-1}, the crosses CML-451 X BML-6, LM-13 X UMI-1200, LM-14 X UMI-1200, LM-14 X IML-187, BML-10 X V-405 were having highest significant and desirable positive SCA effects. These results are in conformity with the results of Satyanarayan *et al*. (1990) and Aslam *et al*. (2017) and signify the importance of non-additive gene action for the inheritance of cob length,cob diameter, kernals rows cob^{-1} and kernals row^{-1}.The specific cross combinations for these traits involved poor x poor, poor x average, average x good and poor x good general combiners. Most of the superior cross combination involved one of the parents as poor combiner.

The cross combinations CML-451 X LM-13,CML-451 XLM-14, BML-6 X BML-10, BML-10 X V-405, UMI-1200 X IML-187and V-405 X IML-187 showed favorable significant and positive SCA effects for grain yield plant^{-1}. The best crosses combination for this trait was BML-10 X V-405 showing highest and superior SCA effect. Such cross combinations need to be exploited in hybrid breeding program. Similar findings for identification of superior hybrids based on SCA effects for grain yield were also reported by Muraya *et al*.(2006), Subramanian and Subbaraman (2006), Beck *et al*. (1991) Ruswandi *et al*. (2015). Devi *et al*. (2007) Gissa *et al*. (2007). From this study, it was found that grain yield was predominantly governed by non-additive gene action as also reported by Shanthi *et al*. (2010), Da-Silva *et al*. (2010), Dass *et al*. (1997), Wani *et al*. (2017), Majid *et al*. (2022).

Thus, the result of the present investigation revealed that in general there was no relationship between GCA effects of the parents and the SCA effects of the single crosses. However, mean performance of single crosses was largely dependent upon the mean performance of the parents involved so high GCA value of parents is no guarantee of high SCA effects of their crosses and the selection of parents should be based on specific combining ability test.

Heterosis

The magnitude of standard heterosis (SH%) for grain yield plant^{-1} over checks, viz., PMH-10 and DHM-117 were estimated for all cross combinations and revealed that most of the cross combinations showed positive SH over both checks (Table 8). The cross combinations,CML-451 X LM-13, BML-10 X UMI-1200, BML-6 X UMI-1200 and BML-10 X V-405 showed highest positive heterosis over both the standard checks (>20 % over PMH-10 and >30 % over DHM-117) followed by cross combinations, CML-451 X BML-6, LM-13 X IML-187 and among above crosses, BML-10 X V-405, LM-13 X IML-187, BML-10 X UMI-100 and CML-451 X LM-13 were also recognized as good specific combiners for grain yield plant^{-1} as they reflected highest significant and positive SCA effects. Singh *et al*. (2010), Kage *et al*. (2013), Amiruzzaman *et al*. (2013) Izhar and Chakraborthy (2013), Ruswandi *et al*. (2015) and

Table 8. Heterosis estimation over standard checks (PMH-10 and DHM-117) for grain yield plant^{-1} in maize (*Zea mays* L.).

Crosses	Grain yield plant^{-1}(g)	Heterosis over PMH-10 (%)	Heterosis over DHM-117 (%)
CML-451 X LM-13	165.43	26.72	35.08
CML-451 X LM-14	157.93	20.98	28.95
CML-451 X BML-6	164.93	26.34	34.67
CML-451 X BML-10	137.33	5.20	12.13
CML-451 X UMI-1200	154.03	17.99	25.77
CML-451 X V-405	132.93	1.83	8.54
CML-451 X IML-187	113.83	-12.78	-7.05
LM-13 X LM-14	151.53	16.08	23.73
LM-13 X BML-6	127.43	-2.38	4.05
LM-13 X BML-10	148.70	13.91	21.4
LM-13 X UMI-1200	160.83	23.20	31.32
LM-13 X V-405	156.76	20.09	28.03
LM-13 X IML-187	164.63	26.11	34.42
LM-14 X BML-6	160.60	23.02	31.13
LM-14 X BML-10	126.36	-3.19	3.18
LM-14 X UMI-1200	151.50	16.05	23.70
LM-14 X V-405	126.13	-3.37	2.99
LM-14 X IML-187	122.23	-6.36	-0.19
BML-6 X BML-10	163.20	25.01	33.25
BML-6 X UMI-1200	165.10	26.47	34.80
BML-6 X V-405	133.20	2.03	8.76
BML-6 X IML-187	155.33	18.99	26.83
BML-10 X UMI-1200	165.60	26.85	35.21
BML-10 X V-405	164.833	26.27	34.59
BML-10 X IM L-187	92.96	-28.78	-24.09
UMI-1200 X V-405	117.66	-9.86	-3.92
UMI-12OO X IML-187	165.00	26.39	34.72

Table 8. Continued.

Crosses	Grain yield plant^{-1}(g)	Heterosis over PMH-10 (%)	Heterosis over DHM-117 (%)
V-405 X IML-187	161.76	23.92	32.08

Kumar *et al*. (2014) also reported positive economic heterosis in maize for grain yield. Top ranking heterotic crosses for this trait was cross between low × high GCA parents. The crosses, BML-10 X IML-187, CML-451 X IML-187, UMI-1200 X V-405 and LM-14 X IML-187 showed negative heterosis over both the standard checks.

CONCLUSION

It has been revealed that there was highly significant differences among parents and their crosses for all the traits, indicating the diverse nature of the experimental material used in the study. This can serve as viable source material for future breeding programs. None of the parents was found to be a good general combiner for all the characters under consideration but several parents depicted good general combining ability in a desirable direction. Similarly, none of the cross combinations exhibited significant SCA effects for all the traits in a desirable direction. However, there were several cross combinations which demonstrated significant SCA effects in desirable direction for maturity and yield traits. Parents with significant and negative GCA for silking, tasseling and maturity may be considered as potential lines for development of medium maturing hybrids in future programs. The crosses with significant and positive SCA effects for grain yield and other yield attributing traits may be regarded as good specific combiners and can be used for developing high yielding hybrids.The best performing crosses, viz., CML-451 X LM-13, BML-6 X UMI-1200, BML-10 X UMI-1200 and BML-10 X V-405 with maximum standard heterosis for grain yield plant^{-1} should be further evaluated over locations for stability.

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