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Research Article

Combining ability studies for grain yield other agronomic traits in maize (*Zea mays* L.)

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Abstract

The present study was aimed to investigate combining ability among twelve elite maize inbred lines in a complete diallel mating design for twelve yield and yield contributing traits. Twelve parents along with their 132 F_1's including reciprocals were planted in a randomized complete block design with three replications. The analysis of variance indicated significant differences among parents for most of the traits studied except for ear diameter. Variance due to GCA and SCA were highly significant for the traits studied indicating importance of both additive and non-additive types of gene action. Preponderance of additive gene action was observed for most of the traits studied except for the grain yield plant^{-1}, number of kernel rows ear^{-1}, number of kernels row^{-1} and ear length which showed preponderance of non-additive gene action. Parent P10 was the best general combiner for grain yield followed by P9 and P1. Parent P9 was also found to be best general combiner for the all traits studied including grain yield. Parent P10 was also found to be best general combiner for early maturity, number of kernel rows ear^{-1} and 100 kernels weight. For the trait early maturity parent found to be best general combiners were P10, P3 and Parent P7. Total 79 cross combinations were possessing significant desirable SCA effects for grain yield. The top cross combinations possessing significant desirable SCA effects for grain yield were P2 x P6, P7 x P8, P3 x P7 and P7 x P9 which may be used for obtaining high yielding hybrids in maize.

Key words

Maize, Inbred Lines, Combining Ability, Full Diallel

Introduction

Maize is one of the most important cereal crops of the world with highest production and productivity after by rice and wheat. Globally it contributes 40% (> 840 mt) to the world food basket annually (FAOSTAT, 2013). Maize provides at least 30% of the food calories together with rice and wheat to more than 4.5 billion people in 94 developing countries (Shiferaw *et al.* 2011). It is also contributes to food security issues in most of the developing countries. In India, maize production has nearly doubled from approximately 12.0 million tons in the early 2000s to around 22.5 million tons today (India Maize Summit 2014). This remarkable production growth has been largely driven by adoption of single cross hybrids, which offers the maximum chance for exploitation of heterosis for all the traits in compression to double, triple and other type of crosses combinations in maize (Das *et al.* 2012). Maize reveals heterosis for all traits and the extent of heterosis is found to be significantly variable depending on the selection of parents and the traits under consideration. A full diallel analysis, provide information on heterosis, maternal effects, GCA and SCA effects of parents in crosses (Glover *et al.* 2005). Combining ability analyses are extensively applied in maize breeding programs to resolve GCA and SCA information of maize germplasm for detection of nature of genes action implicated in the expression of quantitative traits, for selection of valuable parental lines for hybridization, estimation of heterosis, classification of germplasm into different heterotic groups, development of hybrid verities and assessment of genetic diversity (Barata and Carena 2006; Fan *et al.*, 2008 and Bello and Olaoye, 2009). The present investigation is therefore, aimed to understand the role of combining ability effects contributing towards grain yield and other important traits in maize inbreds.

Materials and method

The material under present investigation consisted of twelve maize inbred lines *viz.*, DM-RIL-47, NAI-147, CM-142-393-1, MGUD-38, CM-212-3142, CML-152-3058, SE-547, BLSB-RIL-92, VQL-1, HKI-193-1, HKI-209 and HKI-287 designated as P1, P2 …. P12, respectively, which were selected on basis of agronomic performance and pedigree information. These lines were crossed in a full diallel mating design in *Kharif* season 2009. A total of 144 entries comprise of twelve parent and their 132 resulting F_1's (including reciprocals) were evaluated in a randomized block design in *Rabi* season 2009-10 in three replications at agricultural research farm of Banaras Hindu University, Varanasi, India. Each entry was planted in a single row 3m length adjusted with 15 plants in each replication. Rows were spaced 0.75m apart with 0.25m plant to plant distance. The standard packages of agronomical practices were followed to raise a healthy experimental maize crop. Data were recorded on five randomly selected plants for twelve yield and yield contributing traits *viz.*, days to 50% silk, days to

50% tassel, days to 75% maturity, plant height, ear height, ear length, ear diameter, number of kernel rows ear^{-1}, number of kernels row^{-1}, 100 kernels weight, grain yield plant^{-1} and grain yield plot^{-1}. Days to 50% tassel, silk and 75% maturity considered desirable with significant negative GCA effects while remaining traits having positive significant values were desirable. The analysis of variance (ANOVA) was performed according to Steel and Torrie (1980). Combining ability analysis was performed using mean values, following Method I Model I of Griffing's (1956). The t-test was applied to examine the effects of general combining ability (GCA), specific combining ability (SCA) and reciprocal combining ability (RCA). Significant differences between hybrids and parents were detected using the F-test.

Result and discussion

The present investigation was conducted to assess the GCA effects of parental lines and SCA effects of F_1's including reciprocals for twelve yields and yield contributing traits and investigate their usefulness in development of single cross hybrids in maize. GCA effect is an indicator of the relative value of frequency of favourable genes. Thus, the analysis of GCA effects allows identification of superior parents to be used in breeding programs. The SCA effect of two genetically dissimilar genotypes expresses the variation of gene frequencies between them and their divergence. A very high positive or negative GCA values indicate that the parent in question is highly superior or inferior to the other parents in a diallel cross in relation to the performance of progeny (Cruz and Regazzi, 2001). The analysis of variance of mean squares for the different traits have been presented in Table 1 revealed that, all the genotypes were differed significantly for most of the traits studied. The ANOVA (Table 2) for combining ability revealed that GCA variance was higher than the SCA variance for majority of the traits studied except ear length, number of kernels row^{-1} and grain yield plant. The preponderance of GCA variance expressed the role of additive gene effects, while the predominance of SCA denotes the higher influence of non-additive gene effects Kadlubiec *et al.* (2001) and Sara *et al.* (2014). The mean squares of GCA and SCA were significant ($p < 0.001$) for these traits indicated the importance of both additive and dominance gene effects. Significant ($p < 0.05$) reciprocal differences were also observed for some traits *viz.*, in days to 75% maturity, plant and ear height, number of kernels row^{-1} and grain yield plant^{-1}.

An over view of table 3 revealed that except P9 all other parents did not appear as best general combiner for all the traits together. The estimate of GCA effects of different maturity traits like days to 50% tassel and silk and 75% maturity found to be varied from -2.70 (P3) to 2.88 (P2), -2.64 (P3) to 2.94 (P11) and -3.29 (P3) to 4.91 (P11), respectively. Parental lines *viz.*, P3, P7, P5 and P10 showed highest negatively significant GCA effects for days to 50% tassel and silk and 75% maturity as compared to other parents, therefore crosses could be desirable for earliness. GCA effects for plant and ear height ranged from -10.32 (P7) to 11.61 (P3) and -7.65 (P11) to 8.40 (P3), respectively. The parental lines P3, P4 and P9 found to be desirable for these traits. Similarly, for ear length and diameter, GCA effects ranged from -0.56 (P11) to 0.40 (P3) and -0.36 (P12) to 0.30 (P10), respectively. Parents P3, P9 and P10 for ear length and diameter found to be good general combiner on the basis of GCA effects. For number of kernels row ear^{-1} and kernels row^{-1} GCA effects ranged from -0.71 (P11) to 1.44 (P10) and -1.10 (P11) to 1.50 (P9), respectively. Based on the GCA performance parents P10 and P9, kernel rows ear^{-1} and kernels row^{-1} revealed good performance for these traits. An observations of traits *viz.*, 100 kernels weight, grain yield plant^{-1} and grain yield plot^{-1} showed that, GCA effects varied from -1.27 (P1) to 1.17 (P10), -3.04 (P1) to 5.01 (P9) and -0.06 (P6) to 0.08 (P10), respectively. Our findings are in close with the result obtained by Hemalatha *et al.* (2014) and Sara *et al.* (2014). Among twelve parental lines, P10 and P9 were found to be good general combiner for 100 kernels weight, grain yield plant^{-1} and grain yield plot^{-1} as compared to other parents.Therefore, these parental lines could be used in maize breeding programs for exploitation of heterosis for the concerned traits.

The SCA effects of maturity traits like 50% tassel, silk and 75% maturity ranged from -5.25 (P1 x P8) to 4.40 (P2 x P6), -5.61(P1 x P8) to 4.34 (P2 x P6) and -8.30 (P1 x P8) to 7.03(P2 x P6) respectively. The study for early behaviour of 132 crosses revealed that, eighteen crosses for tassel, seventeen for silk and fifteen crosses for maturity had a significant negative SCA effect which is desirable for these traits. The SCA effects ranged from -9.80 (P4 x P7) to 16.38 (P6 x P9) and -7.84 (P5 x P7) to 14.81 (P4 x P5) for plant and ear height respectively. Out of 132 experimental crosses, thirty eight crosses for plant and thirty two crosses for ear height showed positive significant SCA effects for these traits. The SCA effects for ear length and diameter varied from -1.67 (P3 x P10) to 2.35 (P2 x P6) and -0.87 (P2 x P4) to 0.94 (P4 x P8) respectively. The estimates of SCA effects also depicted that, thirty five crosses for ear length and forty crosses for ear diameter had positive significant SCA effects. The amount of SCA effects ranged from -2.08 (P2 x P9) to 2.27 (P4 x P10) and -3.54 (P2 x P9) to 4.79 (P2 x P6) for number of kernel rows ear^{-1} and number of kernels row^{-1} respectively. A perusal of (Table 3) indicated that out of one hundred thirty two crosses thirty one crosses for more number of kernel rows ear^{-1} and twenty three crosses for number of kernels row^{-1} showed positive and significant SCA effects. The estimates of SCA effect varied from -2.60 (P7 x P10) to 3.94 (P7 x P11) for 100 kernels weight, -8.80 (P11 x P10) to 19.91 (P10 x P12) for grain yield plant^{-1} and -0.19 (P8 x P9) to 0.17 (P2 x P6) for higher grain yield plot^{-1}. Among 132 crosses forty four crosses for 100 kernels weight revealed positive SCA effects. Similarly, thirty four and seventy nine crosses showed highly significant and positive SCA effects for grain yield plant^{-1} and grain yield plot^{-1}, respectively. These results are in general agreement with the findings of Katna *et al.* (2005), Kambe *et al.* (2013) and Hemalatha *et al.* (2014).

On the basis of assumption that SCA effects of two inbred lines of different genetic background is found to be greater than those from the same group these twelve Parental lines were selected from different groups. Moll and Stuber (1974) reported that cross combination of any parental lines may create hybrid vigour over the parents, which might be due to dominant, over dominant or epistatic type of gene action. Out of 132 experimental crosses for each of the traits studied the top cross combinations selected on the basis of SCA effects and *per se* performance were P1 x P3, P5 x P9 and P7 x P10 for 50% tassel and silk (each) and P1 x P8, P3 x P7, P7 x P10 and P5 x P7 for days to 75% maturity. The crosses P4 x P5 and P4 x P12 for plant height, P4 x P5, P4 x P12 and P1 x P2 for ear height, P2 x P6, P6 x P10 and P10 x P12 for ear length and P4 x P8, P7 x P9, P2 x P9, and P1 x P2 for ear diameter emerged as promising cross combinations. Similarly, highest SCA effects and *per se* performance was exhibited by the crosses were P4 x P10, P8 x P10 and P2 x P6 for number of kernel rows ear^{-1}, P2 x P6, P10 x P12 and P9 x P12 for number of kernels row^{-1}, P7 x P11, P4 x P10, P8 x P10 and P10 x P12 for 100 kernels weight, P10 x P12, P7 x P11, P11 x P12 and P7 x P11 and P7 x P9 for grain yield plot^{-1}. A critical evaluation of this study with respect to SCA effects and *per se* performance indicated that most of the superior crosses have the involvement of at-lest one good general combiner to get the better specific combination. Similar result was reported by Amiruzzaman *et al.* (2013). As per the data existing in diallel cross analysis and their interactions, indicated predominance of additive gene effects in most agronomic traits which is fixable through normal selection procedures, allowing the selection of superior inbred lines and their exploitation in maize breeding programs. Non-additive type of gene action is not fixable and their presence for controlling traits requires exploitation of hybrid vigour through heterosis breeding. The studies on gene action for different quantative traits could be helpful in adopting suitable breeding methodology for the development of high yielding hybrids in maize.

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Table 1. Analysis of variance for different yield and yield contributing traits in maize

Source of variations	d.f	Days to 50% tassel	Days to 50% silk	Days to 75% maturity	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	No. of kernel rows ear^{-1}	No. of kernels row^{-1}	100 Kernels weight (g)	Grain yield plant^{-1} (g)	Grain yield plot^{-1} (kg)
Replication	2	22.80**	18.09**	101.60**	2.75	46.93**	2.54	0.03	0.04	1.90	0.29	9.09**	0.004**
Genotype	143	42.25**	43.81**	84.20**	509.09**	334.08**	4.84**	0.07	4.69**	35.33**	16.48**	709.02**	0.08**
Parents	11	31.60**	37.15**	96.39**	707.10**	373.43**	6.59**	0.78	6.75**	55.04**	16.39**	419.98**	0.15**
F_1	131	43.14**	44.62**	82.72**	391.17**	195.91**	2.75**	0.60**	4.24**	13.44**	8.72**	166.53**	0.02**
P vs F_1	1	41.83**	11.56**	143.77**	13778.10**	18001.92**	259.88**	13.11**	40.98**	2685.23**	1033.86**	74959.57**	7.50**
Error	286	2.41	1.74	5.43	4.18	8.32	0.52	0.01	0.11	2.85	0.43	35.38	0.00

*,** significant at 5% and 1% levels, respectively.

Table 2. GCA, SCA and reciprocal mean squares for different yield and yield contributing traits in maize

Source of variations	d.f	Days to 50% tassel	Days to 50% silk	Days to 75% maturity	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	No. of kernel rows ear^{-1}	No. of kernels row^{-1}	100 Kernels weight (g)	Grain yield plant^{-1} (g)	Grain yield plot^{-1} (kg)
GCA	11	113.08**	110.19**	231.27**	1359.76**	601.20**	1.96*	0.99	7.31**	14.64**	10.69**	147.87**	0.05**
SCA	66	11.00**	12.62**	20.29**	139.83**	138.21**	2.73**	0.33	2.14**	21.98**	9.80**	467.46**	0.05**
Reciprocal	66	0.66	0.66	1.97**	1.21**	2.88**	0.45	0.01	0.03	1.09**	0.32	19.99**	0.00
Error	286	0.80	0.58	1.80	1.40	2.78	0.18	0.00	0.04	0.95	0.14	11.80	0.00

*,** significant at 5% and 1% levels, respectively.

Table 3. Estimates of GCA effects for different yield and yield contributing traits in maize

S No.	Parents	Days to 50% tassel	Days to 50% silk	Days to 75% maturity	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	No. of kernel rows ear^{-1}	No. of kernels row^{-1}	100 Kernels weight (g)	Grain yield plant^{-1} (g)	Grain yield plot^{-1} (kg)
1	P1	0.22	-0.12	-0.59*	-4.06**	3.24**	-0.01	0.21**	0.02	-0.45*	-1.27**	-3.04**	0.05**
2	P2	2.88**	2.91**	3.61**	-1.05**	0.45	0.09	0.05**	-0.31**	-0.30	-0.58**	-1.51*	0.01**
3	P3	-2.70**	-2.64**	-3.28**	11.61**	8.40**	0.40**	0.17**	0.08*	-0.35	-0.83**	-2.23**	-0.02**
4	P4	-0.57**	-0.53**	-1.82**	9.07**	5.63**	0.04	0.05**	-0.27**	-0.47**	0.05	-1.60*	0.00
5	P5	-1.99**	-1.98**	-2.18**	-1.37**	-4.41**	-0.14	0.02	0.33**	-0.28	0.35**	-0.84	0.00
6	P6	2.64**	2.47**	3.78**	-8.34**	-4.20**	-0.10	-0.06**	-0.03	-0.19	-0.08	-1.10	-0.06**
7	P7	-2.42**	-2.25**	-3.10**	-10.32**	-6.46**	-0.43**	-0.17**	0.14**	-0.64**	0.37**	0.40	-0.03**
8	P8	-1.06**	-0.89**	-0.53*	-2.35**	0.62	-0.03	-0.19**	-0.28**	0.68**	0.03	-0.01	-0.01**
9	P9	-0.76**	-0.74**	-1.15**	8.66**	4.88**	0.28**	0.19**	0.20**	1.50**	0.78**	5.01**	0.07**
10	P10	-1.67**	-1.74**	-3.29**	3.39**	0.47	0.32**	0.30**	1.44**	1.22**	1.17**	4.33**	0.08**
11	P11	2.74**	2.94**	4.91**	-9.87**	-7.65**	-0.56**	-0.22**	-0.71**	-1.10**	-0.05	-0.85	-0.03**
12	P12	2.68**	2.58**	3.65**	4.62**	-0.96**	0.15	-0.36**	-0.60**	0.40*	0.07	1.44**	-0.04**
CD		0.18	0.15	0.26	0.23	0.33	0.08	0.01	.037	0.19	0.07	0.67	0.0008

*,** significant at 5% and 1% levels, respectively

Table 4. Estimates of SCA effects for different yield and yield contributing traits in maize

S.No.	Crosses	Days to 50% tassel	Days to 50% silk	Days to 75% maturity	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	No. of kernel rows ear^{-1}	No. of kernels row^{-1}	100 Kernels weight (g)	Grain yield plant^{-1} (g)	Grain yield plot^{-1} (kg)
1	P1 x P2	0.15	-0.58	-1.11	0.63	0.52	0.41	0.66**	0.09	3.25**	2.57**	10.92**	0.05**
2	P2 x P1	-0.33	0.67	-0.17	-0.60	-2.98*	0.28	-0.05	-0.13	0.08	0.40	-1.87	0.00
3	P1 x P3	-3.78**	-3.86**	-3.89**	-4.51**	1.39	0.60*	-0.48**	-0.30*	1.04	0.56*	5.78**	0.02**
4	P3 x P1	0.50	0.50	-0.50	0.03	1.17	0.63*	-0.11*	0.34**	-0.41	0.08	-2.07	0.01**
5	P1 x P4	-1.74*	-2.30**	-1.68	-1.06	0.62	0.05	-0.12*	-0.09	0.20	-0.75**	-0.36	-0.04**
6	P4 x P1	-0.33	-0.17	0.17	-1.27	-0.63	0.93**	0.08	-0.13	0.60	0.85**	2.83	0.00
7	P1 x P5	-0.49	-0.52	0.68	2.37*	5.96**	0.79*	0.51**	1.12**	0.68	0.31	2.02	0.08**
8	P5 x P1	1.50*	1.50*	-0.50	0.47	-0.07	0.51	-0.04	-0.07	-0.40	-0.54*	-2.73	0.00
9	P1 x P6	2.89**	3.37**	3.56**	-6.02**	-4.38**	-1.38**	-0.47**	-0.53**	-2.37**	-1.79**	-2.10	-0.14**
10	P6 x P1	0.50	0.17	-0.67	0.17	-2.07	0.50	-0.09	0.07	0.32	0.72**	0.25	-0.01**
11	P1 x P7	0.95	1.59*	1.10	4.59**	-0.86	-0.35	0.33**	1.17**	0.05	1.23**	7.60**	0.02**
12	P7 x P1	0.50	0.33	0.33	-0.60	0.40	0.40	0.02	0.34**	-0.08	0.55*	-0.65	-0.01**
13	P1 x P8	-5.25**	-5.61**	-8.30**	0.26	-4.33**	-0.26	-0.44**	-1.80**	-1.66**	-1.47**	1.21	0.05**
14	P8 x P1	-0.33	-0.50	-1.17	0.43	-1.93	-0.08	-0.08	0.00	-0.35	1.42**	-0.18	0.01**
15	P1 x P9	2.79**	3.07**	1.32	-9.78**	8.73**	0.21	0.04	-0.35**	1.23	0.44	2.66	0.08**
16	P9 x P1	0.00	0.33	-0.83	-0.07	-3.67**	0.40	0.10*	0.07	0.70	0.23	0.15	0.01**
17	P1 x P10	0.19	1.07	2.46*	3.02**	-0.42	-0.54	0.34**	0.01	-1.50*	0.13	-1.73	0.09**
18	P10 x P1	0.50	0.67	0.83	1.60	-0.23	-0.03	-0.01	-0.07	-0.08	0.75**	1.01	0.00
19	P1 x P11	2.62**	3.06**	3.09**	11.68**	9.11**	1.21**	-0.04	0.49**	2.30**	-0.35	-0.20	0.01**
20	P11 x P1	0.33	0.00	0.67	0.73	0.29	0.41	-0.11*	-0.13	0.70	-0.05	0.53	0.00
21	P1 x P12	0.18	0.59	1.52	5.39**	5.35**	0.99**	-0.05	0.12	0.28	0.47	1.47	-0.01**
22	P12 x P1	0.50	0.17	1.50	1.77*	-0.97	0.58*	0.02	0.27*	0.78	-0.28	-3.77	0.01**
23	P2 x P3	-0.93	-0.72	1.75	6.19**	4.75**	0.78*	-0.09	-0.37**	0.00	-1.03**	4.81	-0.01**
24	P3 x P2	0.00	-0.67	-0.67	1.73*	0.07	-0.55	-0.02	0.00	-0.63	0.62**	-4.13	0.00
25	P2 x P4	-4.06**	-3.83**	-4.54**	-1.36	-7.45**	-0.98**	-0.87**	-1.49**	-0.34	-1.05**	2.57	-0.02**
26	P4 x P2	0.00	0.33	0.50	0.23	-0.37	-0.40	0.02	-0.13	-0.57	0.20	-2.17	-0.01**
27	P2 x P5	1.03	0.78	-0.18	7.87**	5.57**	1.43**	0.69**	-0.18	3.58**	1.34**	12.28**	0.10**
28	P5 x P2	-0.33	-0.83	-1.83	-0.17	-0.18	0.67*	0.09	0.17	0.55	-0.23	0.00	0.00
29	P2 x P6	4.40**	4.34**	7.03**	2.85**	11.78**	2.35**	-0.03	2.00**	4.79**	2.49**	15.94**	0.17**
30	P6 x P2	0.33	0.17	0.33	-0.03	0.17	0.53	0.02	-0.27*	0.42	0.42	0.70	-0.01**
31	P2 x P7	0.29	0.39	1.07	0.32	-2.37*	0.30	-0.14**	1.57**	-0.39	-0.81**	0.55	0.01**

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Table 4. Contd.,

S No.	Crosses	Days to 50% tassel	Days to 50% silk	Days to 75% maturity	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	No. of kernel rows ear^{-1}	No. of kernels row^{-1}	100 Kernels weight (g)	Grain yield $plant^{-1}$ (g)	Grain yield $plot^{-1}$ (kg)
33	P2 x P8	1.76*	2.03**	0.34	-4.93**	8.86**	0.17	-0.23**	0.13	-1.39	0.70**	-1.52	0.01**
34	P8 x P2	1.33*	0.83	-0.67	-0.62	-0.57	-0.18	-0.02	0.00	-0.03	0.23	4.72*	0.00
35	P2 x P9	1.81*	2.05**	0.63	5.05**	0.23	-0.96**	0.67**	-2.08**	-3.54**	-1.05**	-3.79	0.05**
36	P9 x P2	0.67	0.33	-1.67	0.43	-0.23	-0.20	0.07	0.13	1.07	-0.10	8.23**	0.00
37	P2 x P10	-0.13	0.21	-1.57	3.07**	0.13	-0.02	-0.32**	0.47**	1.82**	-0.15	-3.32	0.04**
38	P10 x P2	-0.50	-0.17	-0.33	0.02	-1.15	-0.25	0.12*	0.07	0.12	-0.17	0.90	0.01**
39	P2 x P11	1.64*	1.20	-0.94	2.39*	1.89	-0.55	-0.02	0.62**	-0.73	1.33**	1.85	0.02**
40	P11 x P2	-0.67	-0.17	-1.50	-0.05	-0.17	0.51	-0.08	0.07	-0.42	-0.32	-3.22	-0.01**
41	P2 x P12	-4.47**	-4.94**	-4.34**	-0.51	-0.69	0.51	-0.06	0.71**	0.43	-0.14	1.77	0.06**
42	P12 x P2	0.83	0.33	0.17	0.70	0.40	0.48	0.18**	0.13	1.02	-0.03	4.79*	0.01**
43	P3 x P4	3.01**	3.89**	2.68*	3.90**	2.53*	-0.95**	0.37**	-0.14	1.24	0.42	3.88	0.04**
44	P4 x P3	-0.50	-0.17	-0.83	-0.23	0.90	-0.13	0.05	0.13	0.50	0.67**	5.18**	0.01**
45	P3 x P5	-1.07	-0.33	-2.29	1.64	1.81	0.18	-0.10*	0.93**	-0.36	-1.50**	-0.88	0.02**
46	P5 x P3	0.00	-0.17	-3.17**	-0.87	-0.53	0.65*	-0.04	0.07	0.30	0.75**	1.45	0.01**
47	P3 x P6	1.14	0.89	0.09	4.31**	-3.24*	0.77*	0.55**	-0.45**	1.50*	1.11**	2.16	0.12**
48	P6 x P3	-0.17	0.50	-0.17	-0.37	0.17	0.48	0.04	-0.07	0.58	-0.23	1.37	0.00
49	P3 x P7	-2.64**	-3.05	-5.71**	10.84**	8.55**	0.46	0.13**	1.45**	3.24**	1.17**	6.27**	0.15**
50	P7 x P3	0.00	0.17	-0.83	0.52	0.03	0.07	0.16**	0.13	-0.13	-0.20	6.40**	0.01**
51	P3 x P8	4.32**	4.27**	3.21**	2.82**	2.51*	0.11	0.08	-0.13	-0.53	-1.56**	-5.77**	0.02**
52	P8 x P3	0.02	0.15	-0.65	-0.87	1.47	0.69*	0.14**	0.00	0.48	0.07	-0.65	0.01**
53	P3 x P9	-2.62**	-3.07**	0.85	-0.85	3.11*	-0.14	-0.47**	-0.80**	0.30	-0.69**	0.86	-0.14**
54	P9 x P3	-0.67	-0.33	0.33	-0.47	2.37*	-0.35	-0.06	-0.07	0.27	-0.22	1.80	-0.01**
55	P3 x P10	-1.72*	-1.73**	-1.01	-6.02**	0.49	-1.67**	0.20**	0.09	-2.35**	-1.17**	-0.40	-0.07**
56	P10 x P3	-0.33	-0.33	0.33	0.10	-0.63	-0.20	-0.05	-0.20	0.33	0.17	4.03	0.00
57	P3 x P11	0.21	0.09	0.45	6.59**	1.61	1.45**	0.66**	0.17	2.20**	3.28**	10.28**	0.08**
58	P11 x P3	-0.67	-0.50	0.33	-0.62	0.03	0.21	0.14**	0.30*	-0.57	-0.13	0.43	0.01**
59	P3 x P12	1.43*	1.45*	0.55	4.19**	5.69**	0.21	-0.07	-0.01	0.98	1.17**	2.44	0.06**
60	P12 x P3	0.17	-0.17	-0.17	-0.93	-1.27	-0.37	0.04	-0.07	-0.18	-0.07	0.75	0.00
61	P4 x P5	2.80**	2.73**	2.42*	12.92**	14.81**	0.76*	0.13**	1.54**	-1.00	-0.61**	-1.96	-0.02**
62	P5 x P4	-0.33	-0.33	0.00	-0.93	-1.30	-0.42	-0.06	0.20	-1.20	0.48	-4.77*	0.00
63	P4 x P6	-3.15**	-3.38**	-5.37**	-1.34	-0.67	-0.73*	-0.18**	0.03	-1.11	1.17**	3.18	0.06**

Table 4. Contd.,

S No.	Crosses	Days to 50% tassel	Days to 50% silk	Days to 75% maturity	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	No. of kernel rows ear^{-1}	No. of kernels row^{-1}	100 Kernels weight (g)	Grain yield plant^{-1} (g)	Grain yield plot^{-1} (kg)
64	P6 x P4	0.67	0.67	-0.83	0.37	-0.10	-0.01	0.12*	0.20	0.02	-0.53*	-2.05	0.01**
65	P4 x P7	2.07**	1.34*	3.67**	-9.80**	-0.05	0.69*	-0.05	-0.20	1.50*	0.15	3.35	0.08**
66	P7 x P4	0.83	0.33	0.33	-1.40	-1.07	-0.41	-0.03	-0.13	-0.13	-0.02	-1.82	0.00
67	P4 x P8	-1.12	-1.19	-0.73	0.07	2.88*	0.26	0.94**	-1.45**	1.23	1.08**	7.63**	0.04**
68	P8 x P4	1.00	0.50	1.17	-0.97	-1.80	0.02	-0.06	0.00	0.82	0.25	1.42	0.01**
69	P4 x P9	1.92*	2.66**	2.39	6.46**	2.34*	0.43	0.10*	-0.19	1.87**	1.50**	11.33**	0.07**
70	P9 x P4	-0.33	-0.50	0.33	0.37	-0.07	-0.63*	0.10*	-0.07	-0.52	0.12	1.53	0.01**
71	P4 x P10	0.65	1.32	2.20	1.73*	-0.61	0.34	-0.34**	2.27**	0.87	2.21**	4.43	0.10**
72	P10 x P4	-0.50	-0.50	-1.33	1.03	-0.50	0.35	-0.02	-0.03	0.23	0.15	0.47	0.00
73	P4 x P11	-4.42**	-4.36**	-6.85**	-3.61**	-5.43**	0.93*	0.33**	-1.22**	0.04	-1.32**	-2.78	0.02**
74	P11 x P4	-0.50	-0.83	-0.50	-0.17	0.83	-0.68*	0.08	-0.13	0.05	0.20	-0.70	-0.01*
75	P4 x P12	-0.03	-0.16	0.09	11.93**	10.69**	0.33	0.04	0.60**	0.55	-0.11	4.41	0.08**
76	P12 x P4	-0.17	-0.33	0.17	-1.33	-1.83	0.17	-0.07	-0.07	0.43	0.17	4.78*	0.00
77	P5 x P6	0.93	0.90	2.16	0.42	-7.26**	1.13**	0.40**	-0.63**	3.93**	2.10**	9.92**	0.11**
78	P6 x P5	0.67	0.83	0.67	0.17	0.07	0.67*	-0.09	-0.27*	-0.12	0.10	5.22**	-0.01**
79	P5 x P7	-1.85*	-1.88**	-5.30**	-7.03**	-7.84**	-0.16	-0.26**	-0.80**	-1.20	1.74**	0.93	0.06**
80	P7 x P5	0.50	1.00	-0.33	0.20	-0.03	-0.75*	0.00	0.13	0.30	0.82**	3.45	0.01**
81	P5 x P8	1.96*	2.42**	1.46	4.92**	4.17**	0.79*	-0.23**	-0.17	2.09**	1.31**	10.62**	0.10**
82	P8 x P5	0.33	0.33	-0.67	0.98	1.25	0.26	-0.06	0.07	0.23	-0.25	-0.77	0.00
83	P5 x P9	-3.50**	-3.73**	-3.41**	4.96**	1.20	-0.35	-0.07	1.15**	0.93	0.61**	6.88**	0.04**
84	P9 x P5	0.50	0.33	-0.50	-0.43	-0.78	-0.50	0.02	0.32*	-1.20	-0.27	0.68	-0.01**
85	P5 x P10	-0.60	-0.73	-0.44	-5.20**	-0.83	-0.39	0.34**	-2.03**	-0.64	0.13	3.09	-0.01**
86	P10 x P5	0.50	1.33*	1.33	0.83	2.63*	0.83**	0.09	0.37**	1.75**	-0.12	4.85*	0.01**
87	P5 x P11	-0.83	-0.91	2.02	-2.95**	-0.85	-0.66*	-0.56**	0.12	-0.70	1.70**	4.24	0.05**
88	P11 x P5	0.33	0.50	3.33**	0.40	-0.17	-0.30	0.03	0.20	0.23	-0.37	-0.35	-0.01**
89	P5 x P12	-0.61	-0.57	1.77	-1.07	1.46	-1.02**	-0.19**	0.08	-0.79	-1.53**	-2.95	0.03**
90	P12 x P5	-0.83	-0.85	2.82*	1.80*	1.97	0.27	0.13**	0.00	-0.82	-0.48	-4.48	0.01**
91	P6 x P7	0.53	1.34*	1.40	8.81**	8.02**	-0.30	0.22**	-0.64**	-0.99	0.65**	-4.06	0.04**
92	P7 x P6	0.50	0.33	0.33	-0.53	-3.43**	0.02	-0.12*	-0.07	0.30	0.10	0.57	-0.01**
93	P6 x P8	-4.50**	-5.02**	-5.66**	-9.56**	-2.69*	-0.77*	0.19**	-0.02	-0.32	-0.49	0.13	0.04**
94	P8 x P6	0.17	0.67	-1.50	-0.27	-0.33	-0.28	-0.12*	-0.13	-1.05	0.12	-5.18**	-0.01**
95	P6 x P9	-3.96**	-4.34**	-6.21**	16.38**	8.64**	1.15**	-0.34**	1.37**	1.27	0.48	8.68**	-0.11**

Table 4. Contd.,

S No.	Crosses	Days to 50% tassel	Days to 50% silk	Days to 75% maturity	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	No. of kernel rows ear^{-1}	No. of kernels row^{-1}	100 Kernels weight (g)	Grain yield plant^{-1} (g)	Grain yield plot^{-1} (kg)
96	P9 x P6	0.33	0.50	-0.67	0.25	1.00	-0.02	-0.05	0.13	-0.47	-0.13	2.55	0.00
97	P6 x P10	1.78*	1.82**	2.43*	-3.90**	5.56**	1.43**	0.37**	0.06	1.47*	0.90**	8.37**	-0.04**
98	P10 x P6	-0.50	-0.33	-0.50	0.87	1.57	-0.37	-0.09	-0.07	-1.66**	0.58*	1.50	0.01**
99	P6 x P11	0.71	0.98	-0.78	-2.20*	4.80**	-0.02	0.12*	0.48**	0.87	0.99**	2.79	0.13**
100	P11 x P6	0.50	0.17	0.50	0.70	0.57	-0.05	0.02	0.20	-1.10	0.08	-3.70	-0.01**
101	P6 x P12	0.60	1.17	0.16	5.74**	3.25*	-0.50	-0.08	0.17	0.65	-0.76**	3.17	0.13**
102	P12 x P6	1.67*	1.33*	0.50	0.77	0.40	0.83**	-0.04	0.33*	1.42*	-0.42	0.95	0.01**
103	P7 x P8	0.89	0.86	3.71**	6.83**	6.13**	0.44	-0.03	-0.05	3.16**	2.03**	12.95**	0.16**
104	P8 x P7	-0.50	-0.83	0.67	-1.15	-0.47	-0.68*	-0.05	0.13	-0.35	0.35	-3.80	-0.01**
105	P7 x P9	2.60**	2.88**	2.00	2.73**	-2.55*	0.33	0.86**	-0.46**	0.10	1.52**	2.92	0.14**
106	P9 x P7	-0.50	-0.33	0.33	0.82	1.15	0.30	-0.04	-0.07	0.13	-0.18	5.85**	0.01**
107	P7 x P10	-3.17**	-3.62**	-5.69**	2.68**	3.28*	0.78*	-0.48**	-0.11	1.31	-2.60**	-2.19	-0.03**
108	P10 x P7	0.50	0.50	-0.83	-0.33	-0.17	-0.50	0.07	0.07	-1.47*	0.47	0.77	-0.01**
109	P7 x P11	-1.74*	-2.14**	1.43	1.20	7.23**	0.57*	0.16**	0.38**	4.36**	3.94**	18.61**	0.04**
110	P11 x P7	-1.33*	-1.33*	-0.17	-0.20	0.47	-0.64*	0.13**	0.00	-1.03	-0.35	2.65	0.00
111	P7 x P12	0.64	1.24	1.03	-1.42	2.64*	0.66*	-0.07	0.27*	2.06**	0.89**	9.15**	-0.06**
112	P12 x P7	-0.35	0.02	-0.83	2.33*	2.63*	-0.37	0.05	0.13	-0.17	0.42	0.42	0.01**
113	P8 x P9	-3.76**	-3.82**	-4.90**	-3.92**	-1.28	0.12	-0.06	-0.31*	0.89	0.87**	4.51*	-0.19**
114	P9 x P8	0.17	0.67	1.67	1.23	-2.03	-0.99**	-0.10*	-0.07	-2.22**	-0.03	2.30	0.01**
115	P8 x P10	1.31	1.52*	3.24**	3.55**	1.54	1.07**	0.18**	2.25**	2.87**	2.19**	9.53**	0.10**
116	P10 x P8	0.00	-0.67	-0.67	0.23	0.30	0.45	-0.06	0.00	-0.15	0.12	-2.62	-0.01**
117	P8 x P11	1.24	1.67*	2.20	7.71**	4.79**	-0.44	-0.14**	0.80**	-0.96	-0.51*	2.34	0.14**
118	P11 x P8	-0.33	-0.50	-0.17	-1.07	0.23	0.24	-0.04	0.13	0.33	-0.13	1.30	0.00
119	P8 x P12	0.46	0.20	1.63	0.74	1.07	0.00	0.29**	0.69**	0.65	0.91**	-0.19	0.01**
120	P12 x P8	0.50	0.33	0.33	-0.28	-0.03	0.53	0.11*	0.13	0.78	0.27	4.77*	0.00
121	P9 x P10	1.68*	2.03**	2.20	-2.93**	-2.81*	-0.94**	-0.31**	-0.10	-1.70**	0.76**	-5.35**	0.08**
122	P10 x P9	0.67	0.00	0.33	-0.17	-1.02	0.32	0.08	0.27*	0.10	0.13	0.38	0.01**
123	P9 x P11	0.78	0.69	1.82	1.76*	0.47	0.00	-0.28**	0.39*	-0.11	-1.39**	-2.02	0.12**
124	P11 x P9	-0.17	-0.67	-0.17	0.23	0.15	-0.58*	-0.14**	0.07	-1.03	-0.37	-2.10	-0.01**
125	P9 x P12	0.50	0.21	0.92	-3.16**	-3.30*	1.20**	0.35**	0.08	3.42**	1.91**	9.21**	0.04**
126	P12 x P9	0.17	0.17	0.00	-0.23	-0.37	0.68*	0.03	0.00	0.97	-0.05	2.75	0.01**
127	P10 x P11	-0.99	-1.31	-1.87	4.63**	-0.50	0.85**	0.53**	0.95**	1.82**	0.07	7.99**	-0.04**

Table 4. Contd.,

S No.	Crosses	Days to 50% tassel	Days to 50% silk	Days to 75% maturity	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	No. of kernel rows ear^{-1}	No. of kernels row^{-1}	100 Kernels weight (g)	Grain yield $plant^{-1}$ (g)	Grain yield $plot^{-1}$ (kg)
128	P11 x P10	-0.17	0.00	0.33	-1.53	1.47	-0.93**	-0.05	0.00	-1.38	0.08	-8.80**	0.01**
129	P10 x P12	1.07	1.05	-2.94*	9.53**	4.32**	1.40**	0.12*	-0.90**	4.35**	1.87**	19.91**	0.13**
130	P12 x P10	0.50	0.33	0.67	0.35	0.17	-0.05	-0.03	0.00	0.25	-0.67**	4.88*	0.01**
131	P11 x P12	1.00	1.03	-0.48	-0.16	-1.60	0.60*	0.28**	-0.71**	2.90**	1.24**	16.66**	0.06**
132	P12 x P11	-0.17	-0.67	-0.33	-0.77	-0.80	-0.14	-0.05	0.03	0.28	-0.35	-1.48	0.01*
SE for direct cross		0.82	0.70	1.23	1.08	1.53	0.39	0.06	0.18	0.35	0.35	3.15	0.01
SE for reciprocals		0.63	0.50	0.95	0.84	1.18	0.30	0.05	0.14	0.27	0.27	2.43	0.01

*, ** Significant at 5 and 1 per cent level, respectively.