International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2019; 7(3): 4568-4573

Received: 16-03-2019
Accepted: 18-04-2019

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Combining ability studies for yield and yield contributing traits under two different plant densities in maize (*Zea Mays* L.)

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Abstract
A study on combining ability for yield and its contributing traits was done in 10 inbred lines and its 45 F_{1S} using half diallel under optimum (OPD) and high plant density (HPD) environments. The analysis of variance for different characters indicated highly significant differences among treatments for all the characters studied under both the environments which proved suitability of the experimental materials chosen for the present investigation. The analysis of variance for combining ability indicated that mean squares due to GCA were highly significant for all the characters except ear diameter in OPD, whereas, in HPD these were highly significant for all the characters studied. However, the mean squares due to SCA were highly significant for all the characters studied in both the environments. This suggested that both the additive and non- additive gene actions were important for the expression of these traits. Parent P_3 and P_6 in OPD and P_6 and P_{10} in HPD were the most promising parents having high GCA for grain yield. Crosses, P_1 X P_7 and P_1 X P_5 were the best specific combiners for grain yield in OPD and HPD, respectively.

Keywords: Combining ability, GCA, maize, plant density, sca

Introduction
Plant density is one of the most important cultural practices determining grain yield, as well as other important agronomic attributes. Stand density affects plant architecture, alters growth and developmental patterns and influences carbohydrate production and partition (Casal *et al.*, 1985) [5]. Maize is more sensitive to variations in plant density than other members of the grass family (Almeida and Sangoi, 1996) [2]. The use of high populations heightens interplant competition for light, water and nutrients. This may be detrimental to final yield because it stimulates apical dominance, induces barrenness, and ultimately decrease the number of ears produced per plant and kernels set per ear (Sangoi and Salvador, 1998) [15]. Ideally, plants spaced equidistantly from each other compete minimally for nutrients, light and other growth factors (Lauer, 1994) [11]. Maize grain yield declines when plant density is increased beyond the optimum plant density primarily because of decline in the harvest index and increased stem lodging (Tollenaar *et al.*, 1997) [17]. Maize susceptibility to variations in plant density has generated intense research effort with a view to better understand how changes in the number of individuals per unit area impact grain yield definition and to identify optimum population densities for this species under a wide range of environmental and management situations.
Combining ability is the ability of a genotype to transmit its desirable performance to its crosses/ offspring and these studies are necessary to identify superior parents which may be used to build-up a population with favourable and fixable genes for effective yield enhancement. The variance due to general combining ability (GCA) and specific combining ability (SCA) are the measure of extent of additive and non- additive type of gene actions, respectively (Rajesh *et al*., 2018; Bhat and Deshpande, 2018) [13, 4]. The GCA effect of a genotype indicates the relative position of the genotype in terms of frequency of favorable genes and of its dispersion, as compared to other genotypes (Aliu, S 2008). The SCA effect of two genotypes measures the variation of gene frequencies between them and their divergence, as compared to the diallel genotypes (Asif *et al.*, 2015; Zakiullah *et al.*, 2018) [3, 19]. Therefore, the present investigation was done using 45 single cross hybrids developed from 10 parental

lines in a half diallel fashion to estimate general combining ability (GCA) and specific combining ability (SCA) and to identify the promising single cross maize hybrids based on sca effect under two different plant densities.

Material and Methods

The basic experimental material comprised 10 maize inbred lines. Detailed pedigrees of the lines are given in Table 1.

Table 1: Maize inbred lines selected for study

Sl. No.	Pedigree	Pedigree code
1	YHP A ⊗ 85-4-3-2-3-3-1-1-1	P_1
2	YHP -B ⊗45-1-2-3-1-6-9-⊗-1⊗5	P_2
3	Pop31⊗ 18-2-1-1-4-2-2-1/1-⊗-1⊗4	P_3
4	Pop 31⊗ 23-1-1-1-1-2-1/2 # ⊗2-2to 6 #	P_4
5	Pob 445⊗-58-6-3-BBB	P_5
6	Pob 446⊗-47-3-1-B-B-B A⊗	P_6
7	Tarun ⊗61-5-3-1-2-1-1-1⊗-2 ⊗2	P_7
8	Pop31⊗ 18-2-1-1-4-2-2-1/1-⊗-2 ⊗10 A	P_8
9	YHP Pant ⊗ 130-2-3-4-1-2-1-1	P_9
10	CML-226-2-3-2-1-B-B-B-B-B-B	P_{10}

All the 45 F_{1S} (excluding reciprocals) along with 10 inbred lines were evaluated in a randomized complete block design with three replications at N.E. Borlaug Crop Research Centre, G.B.P.U.A.&T., Pantnagar, Uttarakhand under two different environments viz. optimum (66,666 plants/ha) and high plant density (86,666 plants/ha) during *kharif,* 2012. Observations were recorded on the whole plot basis in respect of days to 50 per cent tasselling, days to 50 per cent silking, anthesis-silking interval and grain yield (kg/ha). However, plant height, ear height, ear length, ear diameter, number of kernel rows/ear and number of kernels/row were recorded on the basis of five randomly selected competitive plants and 100-kernel weight was calculated from seeds composited from 5 randomly selected plants from every plot (for F_{1S}, inbred lines and checks). The average values of these plants for all the characters were calculated and used for the statistical analysis. Combining ability analysis was carried out by using the method 2 and model I (fixed effect model) of Griffing (1956) [8]. The mathematical model underlying this analysis is assumed as follows:

$$X_{ij} = \mu + g_i + g_j + S_{ij} + 1/bc \sum k \Sigma I\ e_{ijk}$$

Where,

X_{ij} = Mean of ij^{th} genotype over k block
μ = Population mean
g_i = GCA effect of i^{th} parent;
g_j = GCA effect of j^{th} parent;
S_{ij} = SCA effect of ij^{th} combination such that $S_{ij} = S_{ji}$ and
e_{ijk} = Error associated with the observation X_{ijk}; k = 1, 2, 3,…r
i,j = 1,2……..,p (number of parents)
k = 1,2……..,b (number of replication)

Results and Discussion

The analysis of variance for combining ability (Table 2) revealed that GCA variances were significant for all the characters studied except ear diameter in OPD, whereas in HPD, these were significant for all the traits studied. Likewise, the SCA variances were significant for all the characters in both the OPD and HPD environments. This suggested that both the additive and non- additive genetic variances were important for the expression of the traits studied.

The GCA effects of the parents in the OPD indicated parental lines, P_1 and P_3 to be the best general combiners for four characters each, *viz.*, days to 50% tasselling, days to 50% silking, number of kernel rows/ear and number of kernels/row for P_1 and plant height, ear height, number of kernels/row and grain yield for P_3. In HPD, P_3 exhibited as the best general combiner for eight characters, *viz.*, days to 50% tasselling, days to 50% silking, plant height, ear height, ear length, number of kernels/row, 100- kernel weight and grain yield, followed by P_9 which excelled for GCA among all lines for five characters, *viz.*, days to 50% tasselling, days to 50% silking, number of kernel rows/ear, number of kernels/row and grain yield.

Perusal of Table 3 showed that the parents P_1 and P_5 for days to 50% tasselling; P_1 for days to 50% silking; P_3 and P_6 for anthesis- silking interval; P_6 for plant height; P_2 and P_3 for ear height; P_5 for ear length; P_1 for number of kernel rows/ear; P_1 and P_3 for number of kernels/ row; P_2, P_5 and P_7 for 100-kernel weight and P_3 and P_6 for grain yield were some of the most promising parents having high GCA effects in OPD. In HPD, some of the parents having high substantial good GCA effects were P_7 for days to 50% tasselling; P_3 for days to 50% silking; P_2 for anthesis- silking interval; P_3 for plant height; P_3 and P_6 for ear height; P_6 and P_9 for number of kernel rows/ear; P_3 and P_6 for 100- kernel weight and P_6 and P_{10} for grain yield.

Table 4 revealed that none of the crosses showed good responses for all the characters in both the environments. In OPD, the cross, P_3 X P_6 appeared as best specific combiner for days to 50% tasselling, P_3 X P_6 for days to 50% silking, P_4 X P_7 for anthesis- silking interval, P_2 X P_6 for plant height, P_3 X P_4 for ear height, P_7 X P_8 for ear length, P_2 X P_3 for ear diameter, P_2 X P_3 for number of kernel rows/ear, P_1 X P_{10} for number of kernels/row, P_4 X P_8 for 100- kernel weight and P_1 X P_7 for grain yield. However, in HPD, crosses, P_1 X P_4, P_1 X P_4, P_2 X P_6, P_5 X P_7, P_1 X P_8, P_7 X P_8, P_6 X P_{10}, P_8 X P_9, P_1 X P_7, P_8 X P_9 and P_1 X P_5 were the best specific combiners for days to 50% tasselling, days to 50% silking, anthesis- silking interval, plant height, ear height, ear length, ear diameter, number of kernel rows/ear, number of kernels/row, 100-kernel weight and grain yield, respectively.

Overall results revealed that different crosses exhibited differential response for SCA effects in different environments for all the quantitative characters studied. This means that there were very little or no reproducibility for SCA effects of the crosses in both the environments. It reflects effect of environment on the performance of the crosses. Similar results were earlier reported by Srivastava (2001) [16], Unay *et al*. (2003) [18], Raul *et al*. (2007) [14], Fan *et al.* (2008) [7], Machado *et al.* (2009) [12], Choukan *et al.* (2011) [6], Haddadi *et al*. (2012) [10] and Guerrero *et al*. (2014) [9].

Table 2: Analysis of variance for combining ability for important economic characters in maize under OPD and HPD environments

Source of variation	d.f	Plant density	Days to 50% tasselling	Days to 50% silking	Anthesis-silking interval	Plant Height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	No. of kernel rows/ ear	No. of kernels/ row	100-kernel weight (g)	Grain yield (Q/ha)
General combining ability (GCA)	9	OPD	2.91***	1.91***	1.13***	189.53***	101.07***	0.63**	0.05	0.32*	8.43***	13.35***	129.96***
		HPD	10.10***	6.85***	0.62***	209.58***	95.85***	0.49***	0.20***	1.05***	2.53***	5.26***	181.54***
Specific combining ability (SCA)	45	OPD	3.62***	4.64***	0.38***	84.08***	47.96***	1.15***	0.10**	0.33***	7.54***	6.60***	77.87***
		HPD	6.25***	5.75***	0.27***	115.77***	51.48***	0.60***	0.37***	0.44***	3.49***	4.61***	110.41***
Error	108	OPD	0.47	0.55	0.12	11.53	4.47	0.23	0.05	0.16	1.44	0.78	1.98
		HPD	0.43	0.41	0.09	2.45	1.31	0.13	0.01	0.13	0.63	0.36	1.34

Significance Levels * = <.05, ** = <.01 and *** = <.001; OPD= optimum plant density; HPD= high plant density

Table 3: Estimates of GCA effects of parents for important economic characters in maize under OPD and HPD environments

GCA	Days to 50% tasselling		Days to 50% silking		Anthesis- silking interval		Plant height (cm)		Ear height (cm)		Ear length (cm)	
	OPD	HPD	OPD	HPD	OPD	HPD	OPD	HPD	OPD	HPD	OPD	HPD
P_1	-0.89***	0.85***	-0.73***	0.76***	0.08	-0.09	1.73	0.91*	0.52	2.61***	0.05	-0.07
P_2	-0.08	1.04***	-0.07	0.70***	-0.06	-0.34***	2.76**	-0.11	1.87**	0.46	-0.05	-0.24*
P_3	0.25	-1.21***	-0.32	-1.08***	-0.51***	0.18*	6.87***	7.83***	5.61***	4.63***	0.19	0.23*
P_4	0.11	-0.87***	-0.15	-0.80***	-0.26**	0.13	-2.30*	-4.36***	-0.85	-2.56***	-0.03	-0.14
P_5	-0.44*	-0.40*	0.07	-0.16	0.52***	0.24**	-0.49	-3.54***	0.22	-0.34	0.44**	0.07
P_6	0.50**	0.24	0.21	0.26	-0.28**	-0.01	3.01**	5.16***	2.55***	1.59***	0.00	-0.12
P_7	-0.25	-0.48**	-0.07	-0.22	0.19*	0.27**	-4.13***	-6.01***	-4.67***	-5.29***	-0.06	-0.28**
P_8	-0.11	-0.15	0.18	-0.27	0.36***	-0.15	-6.82***	-0.58	-2.11***	1.57***	-0.47***	0.30**
P_9	0.89***	-0.65***	0.82***	-0.52**	-0.06	0.13	-2.05*	0.43	-2.59***	-1.66***	0.00	0.05
P_{10}	0.03	1.63***	0.04	1.34***	0.02	-0.34***	1.42	0.27	-0.56	-1.03**	-0.08	0.20*

Contd. Table 3

GCA	Ear diameter (cm)		No. of kernel rows/ ear		No. of kernels/ row		100- kernel weight (g)		Grain yield (Q/ha)	
	OPD	HPD	OPD	HPD	OPD	HPD	OPD	HPD	OPD	HPD
P_1	0.01	-0.01	0.25*	0.31**	1.02**	-0.24	-0.34	-0.07	-3.19***	-2.85***
P_2	0.02	-0.02	0.17	0.18	-0.68*	-0.66**	1.60***	0.03	-3.00***	-2.89***
P_3	0.08	-0.01	-0.01	-0.35***	0.67*	0.69**	-0.17	0.88***	1.20**	3.72***
P_4	-0.03	-0.04	-0.16	-0.04	0.02	0.01	-1.57***	0.27	0.76	-0.77*
P_5	-0.05	-0.21***	-0.20	-0.57***	0.32	-0.50*	1.05***	0.09	-0.80*	-2.39***
P_6	0.10	-0.13***	-0.08	0.33**	0.56	0.33	0.07	0.96***	8.32***	4.47***
P_7	0.03	0.03	0.09	0.03	-0.90**	-0.41	1.31***	0.09	-1.06**	-3.19***
P_8	-0.14*	0.21***	-0.20	0.10	-1.70***	-0.10	-0.67**	-0.93***	-2.15***	-4.85***
P_9	-0.01	-0.02	0.16	0.21*	0.42	0.52*	-1.26***	-1.12***	-0.65	2.45***
P_{10}	-0.01	0.19***	-0.01	-0.20*	0.28	0.35	-0.01	-0.20	0.56	6.31***

Significance Levels * = <.05, ** = <.01 and *** = <.001; OPD= optimum plant density; HPD= high plant density

Table 4: Estimates of SCA effects of crosses for important economic characters in maize under OPD and HPD environments

Cross	Days to 50% tasselling		Days to 50% silking		Anthesis- silking interval		Plant height (cm)	
	OPD	HPD	OPD	HPD	OPD	HPD	OPD	HPD
P_1 X P_2	0.58	0.79	0.73	1.07	-0.69*	0.28	0.46	11.75***
P_1 X P_3	1.91**	-2.29***	2.31**	-2.49***	0.42	-0.25	-8.32*	6.01***
P_1 X P_4	1.05	-4.29***	2.14**	-3.77***	1.17***	0.47	-15.15***	-12.46***
P_1 X P_5	1.61*	-2.77***	1.92**	-3.07***	0.39	-0.31	-0.62	1.38
P_1 X P_6	-2.34***	2.26***	-2.88***	1.84**	-0.47	-0.39	3.21	15.01***
P_1 X P_7	-1.92**	2.65***	-1.94**	2.32***	0.06	-0.34	11.35***	-0.81
P_1 X P_8	1.27*	-2.02**	1.48*	-2.30***	0.23	-0.25	-0.96	16.69***
P_1 X P_9	-1.06	2.48***	-2.16**	2.29***	-1.02**	-0.20	5.93	-9.92***
P_1 X P_{10}	-1.20	-0.13	-1.05	0.76	0.23	0.94**	11.79***	16.23***
P_2 X P_3	1.11	-0.49	-0.02	-0.10	-1.11**	0.33	2.65	7.37***
P_2 X P_4	-0.09	-0.49	-0.19	-0.71	-0.02	-0.28	-3.18	-9.44***
P_2 X P_5	0.80	-2.29***	1.59*	-2.68***	0.87**	-0.39	-0.98	5.74***
P_2 X P_6	-1.14	2.07**	-0.22	1.23*	1.01**	-0.81**	15.18***	6.37***
P_2 X P_7	0.27	-3.88***	1.39*	-2.96***	1.20***	0.91**	-7.35*	-3.79*
P_2 X P_8	-0.87	2.12**	-1.19	2.09***	-0.30	0.00	6.34*	5.11***
P_2 X P_9	0.80	-1.71**	1.17	-1.66**	0.45	0.05	-1.10	5.10***
P_2 X P_{10}	-2.34***	0.68	-2.72***	0.15	-0.30	-0.47	5.10	1.59
P_3 X P_4	-2.76***	-0.90	-2.61***	-1.27*	0.09	0.19	12.38***	-3.38*
P_3 X P_5	3.13***	-1.04	3.17***	-0.91	-0.02	0.08	3.90	-3.87*
P_3 X P_6	-4.48***	1.98**	-4.30***	3.01***	0.12	1.00***	6.74*	-3.57*

P_3 X P_7	0.27	-0.96	0.98	-1.18	0.64*	-0.28	12.21***	11.94***
P_3 X P_8	-2.20**	-1.96**	-2.94***	-1.80**	-0.19	0.14	6.90*	-8.49***
P_3 X P_9	-0.53	0.54	-0.58	0.12	-0.11	-0.47	-3.21	-9.51***
P_3 X P_{10}	-1.34*	3.60***	-1.80*	3.26***	-0.52	-0.34	-3.68	-13.35***
P_4 X P_5	-1.06	1.96**	-0.66	1.48*	0.39	-0.53	-3.26	-1.67
P_4 X P_6	1.33*	0.98	1.87**	1.73**	0.53	0.72*	6.24	-5.71***
P_4 X P_7	-2.26***	4.04***	-3.52***	3.87***	-1.27***	-0.22	-3.29	-1.87
P_4 X P_8	3.27***	-0.29	3.56***	-0.41	0.23	-0.14	1.07	15.03***
P_4 X P_9	-0.06	-0.46	-0.41	-0.82	-0.36	-0.42	3.96	-0.98
P_4 X P_{10}	1.80**	-2.07**	1.37	-2.35***	-0.44	-0.28	-11.18***	-1.16
P_5 X P_6	1.55*	-1.49*	0.64	-0.91	-0.91**	0.61*	-0.23	4.47**
P_5 X P_7	1.63*	-3.10***	2.26**	-2.77***	0.62	0.33	-0.76	19.31***
P_5 X P_8	-0.51	1.57*	-0.99	1.95**	-0.55	0.41	-2.41	-5.12***
P_5 X P_9	-1.17	-4.27***	-0.63	-3.13***	0.53	1.14***	11.82***	4.40**
P_5 X P_{10}	-2.98***	1.79**	-4.19***	1.68**	-1.22***	-0.06	1.35	-13.64***
P_6 X P_7	-0.31	-0.74	-0.22	-1.18	0.09	-0.42	-7.93*	-2.73
P_6X P_8	0.22	-2.07**	0.53	-1.80**	0.26	0.33	5.09	5.17***
P_6 X P_9	0.55	-0.90	0.23	-1.55*	-0.33	-0.61*	-6.68*	10.49***
P_6 X P_{10}	0.08	2.15***	0.67	2.26***	0.59	-0.14	13.85***	-11.02***
P_7 X P_8	-3.03***	3.98***	-3.19***	3.34***	-0.22	-0.61*	4.57	-13.65***
P_7 X P_9	0.63	-1.85**	0.84	-1.41*	0.20	0.44	0.79	-9.33***
P_7 X P_{10}	-0.84	1.87**	-0.72	1.40*	0.12	-0.42	4.65	-12.64***
P_8 X P_9	-0.84	-0.85	-0.74	-1.68**	0.03	-0.81**	10.48**	-3.43*
P_8 X P_{10}	-0.98	1.54*	-0.97	1.79**	-0.05	0.00	9.34**	-1.14
P_9 X P_{10}	2.02**	-1.63**	2.39**	-1.96**	0.37	-0.28	-15.43***	-5.28***

Contd. Table 4

Cross	Ear height (cm)		Ear length (cm)		Ear diameter (cm)		No. of kernel rows/ear	
	OPD	HPD	OPD	HPD	OPD	HPD	OPD	HPD
P_1 X P_2	-0.46	0.73	-0.52	-0.43	0.05	0.60***	0.04	0.57
P_1 X P_3	-6.53**	8.23***	-0.63	-0.20	0.03	0.59***	-0.11	0.17
P_1 X P_4	-14.07***	4.75***	-0.27	-0.23	0.31	-0.55***	0.64	-0.14
P_1 X P_5	5.19*	-0.47	-1.01*	0.53	-0.11	-0.47***	0.61	1.05**
P_1 X P_6	6.53**	3.61**	0.16	1.08**	-0.06	-0.66***	-0.04	0.02
P_1 X P_7	6.08**	5.82***	1.96***	-0.02	0.11	-1.02***	-0.75*	0.72*
P_1 X P_8	-9.81***	13.95***	-1.03*	1.36***	0.14	0.50***	0.21	0.32
P_1 X P_9	6.33**	-4.15***	0.13	-0.65	-0.11	0.00	-0.02	-0.53
P_1 X P_{10}	6.97***	-0.45	0.44	0.83*	0.39	0.29*	-0.24	-0.51
P_2 X P_3	-1.88	2.72*	2.30***	0.27	0.78***	-0.88***	1.30***	-0.37
P_2 X P_4	-1.22	3.90***	0.33	-0.42	0.12	-0.94***	-0.16	0.39
P_2 X P_5	-1.49	10.68***	0.39	1.40***	-0.20	0.56***	0.29	0.45
P_2 X P_6	5.84**	2.09	1.39**	0.43	0.45*	-0.15	-0.77*	-0.91**
P_2 X P_7	-13.94***	-2.37*	-1.14*	-2.25***	0.06	0.29*	0.12	-0.35
P_2 X P_8	5.18*	2.44*	-0.40	0.54	-0.21	0.24*	-0.11	0.65
P_2 X P_9	-3.35	0.67	-0.60	-0.04	-0.06	0.43***	0.19	0.00
P_2 X P_{10}	-1.05	6.04***	-0.79	0.08	-0.40	-1.01***	0.10	-0.25
P_3 X P_4	10.18***	-1.60	0.42	0.50	-0.10	0.44***	-0.24	0.52
P_3 X P_5	-0.56	-0.82	0.85	-0.03	-0.02	-0.71***	-1.06**	-0.82*
P_3 X P_6	0.78	-8.41***	-0.85	0.08	-0.03	-0.30*	-0.18	-0.25
P_3 X P_7	4.00*	2.47*	0.22	0.64	-0.13	0.47***	0.65	0.11
P_3 X P_8	8.78***	1.94	0.70	-0.74*	0.47*	-0.98***	0.81*	-0.22
P_3 X P_9	4.58*	5.17***	0.29	1.08**	-0.18	0.19	-0.36	-1.07**
P_3 X P_{10}	-7.45***	-2.13*	-2.96***	-1.53***	-0.15	0.28*	-0.58	-0.52
P_4 X P_5	-3.44	-6.63***	-1.39**	-0.44	-0.01	0.62***	-0.18	0.74*
P_4 X P_6	-0.10	-4.22***	0.98*	-0.91**	-0.32	0.17	-0.04	-0.62
P_4 X P_7	-3.88	-6.95***	-1.02*	-0.32	-0.11	0.21	-0.48	-0.53
P_4 X P_8	0.56	11.46***	-1.28**	-0.53	-0.18	0.19	-0.18	-0.86*
P_4 X P_9	2.04	-2.31*	0.05	-0.48	0.06	-0.64***	-0.55	-0.84*
P_4 X P_{10}	-0.66	-4.94***	0.49	0.44	0.00	-1.05***	0.30	0.64
P_5 X P_6	-3.84	11.23***	1.67***	-0.55	0.36	-0.32**	0.14	-0.70*
P_5 X P_7	0.05	7.50***	-0.30	-0.03	0.33	0.58***	0.10	0.00
P_5 X P_8	-2.17	-6.10***	-0.18	-0.74*	-0.17	0.57***	0.40	0.07
P_5 X P_9	1.97	-0.20	0.71	-0.39	0.57**	-0.67***	0.43	0.02
P_5 X P_{10}	3.94*	-5.50***	-0.35	-0.47	-0.09	0.59***	-0.33	-0.16
P_6 X P_7	-2.95	1.51	-1.06*	0.00	0.52*	-0.67***	1.05**	0.57
P_6X P_8	8.50***	8.32***	-1.45**	-0.12	-0.42*	-0.45***	-1.06**	-0.10
P_6 X P_9	-11.70***	1.88	0.31	0.60	-0.31	-0.39**	0.44	-0.55
P_6 X P_{10}	8.61***	-8.62***	0.16	-0.01	0.39	0.84***	0.42	0.00

P_7 X P_8	4.72*	-14.81***	2.59***	1.44***	0.19	0.16	0.84*	-0.81*
P_7 X P_9	-0.47	-6.38***	-0.29	-0.51	-0.47*	-0.51***	-0.13	-0.78*
P_7 X P_{10}	9.83***	1.79	0.42	0.71*	-0.13	-0.26*	0.45	0.17
P_8 X P_9	8.64***	-4.77***	0.69	-0.19	-0.04	-0.16	0.76*	1.42***
P_8 X P_{10}	5.28**	3.59**	0.44	-0.70*	-0.03	0.06	0.47	-0.03
P_9 X P_{10}	-4.25*	9.83***	0.00	0.05	0.61**	0.43***	0.17	0.52

Contd. Table 4

Cross	No. of kernels/ row		100- kernel weight (g)		Grain yield (Q/ha)	
	OPD	HPD	OPD	HPD	OPD	HPD
P_1 X P_2	-2.39*	-2.13**	-0.07	-0.91	-2.04	1.35
P_1 X P_3	-4.06***	-0.41	0.78	2.46***	-16.69***	-9.66***
P_1 X P_4	-3.35**	-2.33**	-0.65	-1.03	-4.53**	12.35***
P_1 X P_5	1.88	2.38**	-0.59	0.21	6.00***	24.63***
P_1 X P_6	0.91	2.15**	1.40	1.60**	-3.02*	-3.81***
P_1 X P_7	2.70*	2.76***	-2.74**	-0.13	16.92***	9.19***
P_1 X P_8	-3.50**	2.71***	-1.43	2.37***	-3.41*	11.30***
P_1 X P_9	1.32	-2.24**	4.87***	-3.56***	-0.19	-6.31***
P_1 X P_{10}	6.12***	-0.74	1.28	1.03	8.70***	11.59***
P_2 X P_3	4.57***	1.28	1.82*	2.55***	0.96	3.42**
P_2 X P_4	0.82	-1.65*	1.10	0.21	6.24***	5.69***
P_2 X P_5	-0.55	1.73*	-2.19**	2.19***	1.24	9.02***
P_2 X P_6	1.88	0.70	-0.47	2.31***	7.63***	-8.95***
P_2 X P_7	-4.26***	-3.69***	-2.05*	-2.83***	-7.28***	-2.47*
P_2 X P_8	0.67	-0.47	1.86*	-0.92	4.52**	-1.14
P_2 X P_9	1.09	-1.76*	-4.95***	-2.19***	-5.34***	1.63
P_2 X P_{10}	-3.51**	2.08**	-0.41	3.47***	5.55***	1.32
P_3 X P_4	0.34	-2.39**	-1.71*	1.62**	7.85***	8.04***
P_3 X P_5	0.37	0.12	1.73*	-1.79**	0.91	-9.17***
P_3 X P_6	0.13	1.02	-1.09	-0.71	13.97***	15.52***
P_3 X P_7	1.53	0.23	1.59	-3.17***	6.97***	1.65
P_3 X P_8	0.79	0.12	-1.08	-2.82***	-0.71	8.59***
P_3 X P_9	2.28*	2.50**	1.35	-0.11	-1.03	6.73***
P_3 X P_{10}	-5.32***	-0.33	-4.07***	-1.35*	-11.91***	-10.15***
P_4 X P_5	-2.31*	-0.61	-3.43***	1.61**	0.41	-4.96***
P_4 X P_6	1.11	-0.51	0.21	-3.83***	0.47	-18.65***
P_4 X P_7	-0.62	2.04**	1.22	0.79	3.83**	-4.08***
P_4 X P_8	-0.56	-0.41	4.97***	-2.55***	-1.41	13.03***
P_4 X P_9	2.99**	1.64*	-2.53**	1.37*	-0.03	-0.20
P_4 X P_{10}	-0.14	2.21**	-2.28**	-2.41***	5.39***	1.20
P_5 X P_6	3.28**	0.74	1.10	-0.13	4.74***	-4.25***
P_5 X P_7	-0.73	-1.45	-0.89	3.28***	1.61	12.26***
P_5 X P_8	0.54	-2.57**	-0.27	-1.56**	-8.50***	-0.08
P_5 X P_9	0.35	-0.78	3.36***	0.13	0.83	1.89
P_5 X P_{10}	-1.85	-2.02**	1.18	0.18	7.60***	1.10
P_6 X P_7	-4.70***	-2.88***	-1.38	0.10	-18.31***	9.08***
P_6X P_8	-2.97*	1.61*	2.32**	2.69***	6.94***	13.92***
P_6 X P_9	-0.29	2.26**	-0.05	0.09	5.68***	13.62***
P_6 X P_{10}	0.45	-3.31***	-2.18*	1.26*	8.75***	-7.56***
P_7 X P_8	3.63**	-0.85	3.37***	1.92**	10.44***	-1.37
P_7 X P_9	1.78	-1.67*	-3.73***	0.78	9.04***	-8.48***
P_7 X P_{10}	2.64*	1.37	1.90*	1.77**	11.85***	1.89
P_8 X P_9	2.98*	-0.38	1.82*	4.02***	4.04**	-3.38**
P_8 X P_{10}	3.18**	-0.75	1.83*	0.34	-0.12	0.37
P_9 X P_{10}	-0.74	0.43	3.69***	-2.37***	0.06	-4.52***

Significance Levels * = <.05, ** = <.01 and *** = <.001

OPD= optimum plant density; HPD= high plant density

Conclusion

The present study revealed that both the additive and non-additive genetic variances were important for the expression of the traits studied. Bi-parental mating and/or Diallel selective mating which allow intermating of selections in different cycles to exploit both additive and non-additive components of gene effects could be useful in genetic improvement of maize. Inclusion of F1 hybrids showing high SCA and having parents with good GCA, into multiple crosses, could be a helpful approach for improvement of grain yield in maize.

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