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HETROSIS AND COMBINING ABILITY OF SUB TROPICAL MAIZE INBRED LINES

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ABSTRACT

Govind Ballabh Pant University of Agriculture and Technology, India has developed a wide array of subtropical maize (*Zea mays* L.) germplasm, which are well adapted to the subtropics, resistant to major diseases of maize, mature early and are capable of surviving frost that usually comes late in the cropping seasons. The objective of this study was to determine the combining ability of subtropical maize inbred lines and identify appropriate germplasm for hybrid development. P6 was the highest yielding parent and P2 x P7 was the highest yielding cross. Heterosis for grain yield was high in those involving P6 as a parent. Parents P2, P7 and P8 showed significant positive GCA effects and the rest had significant negative GCA effects for gain yield. Parents P2, P7 and P8 could be used for initiating hybrid development work. For grain yield, P1 x P8 was the best specific combiner followed by P5 x P7, P2 x P7, P3 x P4 and P2 x P8 crosses. P7 and P8 manifested a high positive SCA effect with P2, implying that these two lines combine well with P2.

Key Words: General combining ability, heterrosis, *Zea mays*

RÉSUMÉ

L'Université d'Agriculture et de Technologie de Govind Ballabh Pant en Inde, a développé une large gamme de variétés de maïs subtropical (*Zea mays* L.), ces variétés sont bien adaptées au climat subtropical, elles sont résistantes aux pathologies majeures du maïs, elles ont une maturité rapide et sont capable de survivre dans la gelée qui habituellement tombe tard dans la saison culturale. L'objectif de cette étude était de déterminer les habiletés combinatoires de lignées pures de variétés de maïs subtropical et d'identifier des variétés qui peuvent être propices à la création de variétés hybrides. La variété subtropicale P6 a été le parent plus productif et le croisement des parents P2 x P7 avait la plus grande performance. L'hétérosis pour le rendement en grain était élevée dans les croisements incluant le parent P6. Les parents P2, P7 et P8 ont présenté un effet positif de l'habileté combinatoire générale (GCA) et les autres parents présentent un effet négatif de GCA pour le rendement en grain. Les parents P2, P7 and P8 pourraient être utilisés pour initier des programmes d'amélioration variétale visant à créer des variétés hybrides. Pour le rendement en grain, le croisement P1 x P8 a présenté la meilleure habileté combinatoire spécifique (SCA), il est suivi respectivement par les croisements P5 x P7, P2 x P7, P3 x P4 and P2 x P8. Les parents P7 et P8 présentent l'effet positif le plus important de SCA avec P2, ceci implique que ces deux variétés combinent bien avec le parent P2.

Mots Clés: habileté combinatoire générale, hétérosis, *Zea mays*

INTRODUCTION

Maize (*Zea mays* L.) occupies a prestigious place in world agriculture. It is a miracle crop in view of its widespread usage as food and non-food items. Maize can be grown over a diverse geographical environment compared with other crops. Globally, maize is grown over 147 million hectares, with production of approximately 692 million tonnes (FAO, 2005). Maize originated in the tropics and its natural habitat is in the tropics; however, the crop is grown in the warmer parts of temperate, humid, subtropical and in highlands. This puts greater challenge to the maize breeders in developing suitable maize varieties/hybrids best suited for a wide range of growing conditions. An efficient breeding programme, which in turn will depend upon the information on different genetic components and variations, leads to the identification of best parents, which can deliver the desirable hybrids. The development of high yielding and widely adapted hybrids of maize depends on, among other things, performance of the inbred lines and their combining ability for yield and traits contributing to yield. Information about combining ability of parents and crosses facilitates breeders in the selection and development of single cross hybrids (Leta *et al.*, 2006).

To establish a sound basis for any breeding programme, breeders must have information on the nature of combining ability of parents, their behaviour and performance in hybrid combinations (Chawla and Gupta, 1984). Combining ability of an inbred line refers to its ability to produce superior hybrids, in combination with other inbreds or strains. General combining ability (gca) is the average performance of a genotype in series of crosses; whereas specific combining ability (sca) rests on the deviation predicted on the basis of the average performance. General combining ability (gca) is associated with additive genetic effects, while sca is related to non-additive (dominance, epistatic and genotype x environment interaction) effects (Falconer, 1989). Although such genetic studies have been undertaken on maize for other potential areas (Leta *et al.*, 2006), little effort has been done to gather information for subtropical areas in north India. The objective of this study was to determine the combining ability of subtropical maize (*Zea mays* L.) inbred lines and identify appropriate germplasm for hybrid development.

MATERIALS AND METHODS

A field experiment was conducted at the Govind Ballabh Pant University of Agriculture and Technology, Pantnagar (E_1), Maize Research Centre, Gorakhpur (E_2), and at the Maize Research Centre, Dholi (E_3), both in India. Pantnagar is situated at 29.0°N latitude and 79.3°E longitude and at an altitude of 243.84 m above the mean sea level. The average rainfall at the centre is 830 mm per *annum*. The minimum and maximum temperatures are 20 and 31 °C, respectively.

Dholi is situated at 25.59°N, 85.75°E and 581 m latitude, longitude and altitude, respectively. Gorakhpur is situated at 81.36°E latitude and 27.34°N longitude and at an altitude of 130 m above the sea level; with minimum and maximum temperatures are 21 and 31.5 °C, respectively. Gorakhpur receives an average annual rainfall of 800 mm per *annum*. The soil type of experimental fields was clay loam for Pantnagar and Gorakhpur, and sandy loam for Dholi.

The maize genotypes used comprised of 8 elite lines, obtained from Govind Ballabh Pant University of Agriculture and Technology in India. Detailed pedigree of the materials is shown in Table 1. This study was undertaken with eight inbred lines, which were initially screened for various desired characters, and grown for seed multiplication through selfing during winter 2006 at Crop Research Centre, Pantnagar. These inbred lines were then crossed in all possible combinations, in half diallel fashion, at Winter Nursery Centre, Agricultural Research Station, Amberpet, Hyderabad, India, during Summer 2006-07 to generate F_1s. All possible 28 F_1s, excluding reciprocals, along with 8 parents and one check (Decan), were evaluated in randomised complete block design, with three replications at the three locations. Plot size was 5 m x 0.75 m.

Two seeds per hill were planted at a spacing of 25 cm within row and 75 cm between rows. After 30-35 days of sowing, the seedlings were thinned to one plant per hill. Crop management practices such as weeding, watering, fertiliser

TABLE 1. Designation and pedigree of inbred lines of maize used in this study

Parents	Pedigree	Designation
1	Pop 31 Ä 21-1-2-4-1-1-1-1/7	Pop3121/7/P1
2	YHP pant Ä 42-1-1-3-2-2-1-1	YHP p42-1/P2
3	Pop 31 Ä 21-1-2-4-1-1-5-1/13	Pop3121/13/P3
4	YHP Pant Ä 10-5-1-1-2-2-3-1	YHP p10/P4
5	Pop31Ä23-1-1-2-2-1-1-1/ 3206#2-1to 3#	Pop3123/P5
6	YHP pantÄ147-1-1-2-2-2-2-1	YHP p147/P6
7	YHP pantÄ42-1-3-1-4-134-4-9	YHP p42-9/P7
8	TarunÄ83-4-3-2	Tarun 83/P8

application, disease and insect pest control were applied as recommended for each location (Lone, 2006). Data were collected on days to 50 per cent tasseling, days to 50 per cent silking, plant height, ear height, ear length, cob diameter, 1000-kernel weight, grain yield, anthesis silking interval, leaf senescence and umber of ears per plant. Leaf senescence was scored using a 1-10 scale (1=10 and 10=100% dead leaf area), three times at one-week intervals, starting from two weeks after 50% female flowering, and averaged. According to Lauer (2002), predicting corn yield prior to harvest is often useful for yield monitor calibration, and for making feed/food supply and marketing decisions. The best and most accurate technique/ method for estimating yield, other than weighing harvested grain from the whole plot, is to harvest and weigh representative samples from a plot area after plants have reached physiological maturity. Lauer (2002) pointed out that to properly calculate yield a researcher has to determine grain moisture, harvested area and grain weight. So, grain yield per hectare was calculated using a shelling percentage of 80%, adjusted to 15%moisture as follows:

After harvesting, ears from each plot were weighed and fresh weight recorded in kg. The moisture content for every plot was determined by "Universal moisture meter", which was adjusted to a uniform moisture level, i.e., 15 per cent. The following formula was used to convert this yield in kg ha^{-1} as per Lauer (2002).

Grain yield (kg ha^{-1}) = Fresh weight ×

$$\left[\frac{100 - moisture}{100}\right] \times \left[\frac{1.176 \times 0.80 \times 10000}{Plot\ size\ (sq.\ m)}\right]$$

Where: 0.80 is shelling percentage = 80/100 and moisture factor = 100/85 = 1.176.

Statistical analysis. The analysis of variance was computed, first for each location separately (data not shown), and then combined across locations using SPAR-1 computer software package. The combined analysis across locations was computed for characters that showed significant difference among the genotypes at either of locations after testing for homogeneity of error variance by using variance ratio. Mean separation was carried out by using LSD (5%).

Combinig ability analysis. The general combining ability (GCA) and specific combining ability (SCA) analyses were computed as described in Griffing's approach through Method 2 and Model I (Griffing, 1956).

RESULTS AND DISCUSSION

Results from the pooled analysis of variance over environments are presented in Table 2. There were significant differences among GCA and SCA effects for grain yield; both GCA (additive) and SCA (non additive) effects were important for the character, thus agreeing with other findings (Nass *et al.,* 2000; Aguiar *et al*., 2003; Qi *et al.,* 2010). This means that it is possible to select parent pairs with breeding potential (de Souza *et al*., 2009) to exploit heterosis to increase productivity in maize. In addition to this, de Souza *et al.* (2009) indicated significant GCA for grain yield. Good general combiners have multiple advantages in that they often have high probabilities of good SCA, allowing for the development of synthetic

TABLE 2. Combining ability effects of parental inbreds for different characters of maize pooled over three environments In India

Sources of variation	d.f.	Days to 50% tasseling	Days to 50% silking	ASI	Plant height (cm)	Ear height (cm)	Ears plant^{-1}	Yield (kg ha^{-1})	Ear diameter (cm)	100 kernel weight (cm)	Ear length	Leaf senescence
GCA	7	4.90**	3.26**	0.76**	174.69**	196.72**	0.002**	0.81**	2.49**	1.38**	6.03**	1103124.7**
SCA	28	11.35**	11.19**	0.68**	1095.35**	164.66**	0.004**	0.58**	7.54**	1.09**	11.51**	1983504.6**
Environment (E)	2	574.201**	609.51**	53.78**	10039.55**	1861.31**	0.01**	6.68**	164.67**	3.99**	341.36**	32080020**
G X E (L)	70	19.33**	30.17**	1.58**	923.11**	238.86**	25.55**	2.46**	101.44**	2.15**	1.14**	2544024.9**
GCA × E	14	2.33**	2.42**	0.40**	110.52**	79.48**	0.002**	1.11**	4.61**	0.60**	6.48**	665849.98**
SCA × E	56	7.59**	7.45**	0.56**	357.02**	79.66**	0.004**	0.78**	3.07**	0.75**	9.026**	89354.24**
Error	210	4.69	5.08	0.16	24.14	8.21	0.001	0.05	0.2	0.35	0.67	3293.43

ASI= Anthesis silking interval. * , ** = Significant at the 0.05 and 0.01 probability levels, respectively

varieties, and are ideal choices as parent in hybrids (Welsh, 1981).

The results revealed significant mean square due to genotypes for all characters studied in this experiment. This suggests that significant differences exist among inbred lines, with respect to combining ability. These findings are similar to the earlier reports (Crossa,1977; Vasal *et al*., 1991; Spaner *et al*., 1996; Joshi *et al*., 1998). The combining ability analysis of diallel data combined overall locations exhibited highly significant environmental differences (P<0.01) for GCA, SCA GCA x environment and SCA x environment effects (Table 2). Significant GCA, GCA x environment effects suggest need for selecting different parental lines for hybrids at specific environments. Similar findings have shown that both GCA and SCA can interact with environments (Machado *et al.,* 2009; Gichuru *et al*., 2011) in yield of maize. These authors reported the significance of the sources of variation of GCA x E and SCA x E, which indicated that both the GCA and the SCA effects varied in the environments assessed.

In line with this view, Kang (1988) indicated that environment played prominent role in phenotypic expression of agronomic characters. The researcher recommended that ignoring environmental components in the fields would likely reduce progress and advances in selection. Thus, environmental factors (rainfall, sunshine, relative humidity, soil, altitude, etc.) could be important factors in breeding for desirable characters including grain yield in the sub tropical maize producing area of India.

The finding that GCA x location interaction was highly significant and greater than SCA x location interaction, is also consistent with other workers (Nass *et al.,* 2000; Paterniani *et al.,* 2000; Bello and Olaoye, 2009). In addition, the interaction SCA by environment was significant for all traits, which allows us to infer that the specific hybrid combinations were not stable across environments (Aguiar *et al*., 2003). This disagrees with the observation of Machado *et al.* (2009). This may be due to difference in the testing locations and the genetic materilas studied.

Mean yield of parents ranged from 554.99 to 1630.58 kg ha^{-1}. P6 was the highest yielding parent

(Table 3). Mean grain yield among crosses ranged from 3296.10 to 722.29 kg ha^{-1}; with the highest yield was obtained from the P2 x P7 cross, and the lowest yield from P1x P4. These results show potential of these specific hybrid combinations for ear yield. A similar result was reported by Aguiar *et al.* (2003), who conducted research on the combining ability of maize grain yield in Brazil. Heterosis for grain yield among the 28 crosses ranged from 4.58 to -82.57%. P3 x P6 and P3 x P4 showed the highest level of heterosis (Table 3).

For days to silk, cross P3 x P6 was the latest (55.00 days), and P6 x P8 as well as P7 x P8 were the earliest (49.00 days). For plant height, crosses fell in wide ranges, as did the parents. P6 x P7 was the tallest cross (165.98 cm) and P3 x P6 was the shortest (123.70 cm) (Table 3). A similar finding was reported by Vasal *et al.* (1991) who worked from Mexico, CIMMYT. For ear length, P7 x P8 was the tallest cross (14.17 cm); while P1 x P2 was the shortest (10.96 cm). Ear height ranged from 69.97cm in cross P1 x P6 to 38.4cm in parent Pop 3123 (Table 2).

For days to tasseling, the means of crosses overall environments ranged from 44.56 days for P7 x P8, to 51.56 days for P3 x P6. For ASI, the single crosses ranged from 2.22 to 4.00, while double crosses ranged from 1.11 to 2.00.

Combining ability analysis. The estimates of GCA effects of parental lines and SCA effects of their hybrids for different characters combined over location are summarised in Tables 4 and 5, respectively. P7 was the best general combiner for grain yield, with highly significant and positive GCA effects (326.08 kg ha^{-1}), followed by P2 (209.61 kg ha^{-1}) (Table 4). This indicates the potential advantage of the parents for development of high-yielding highbred. The only other parent with significant and positive GCA effects for grain yield was P8. Five parents (P1, P3, P4, P5 and P6) had significant, but negative GCA effects for grain yield. When the breeding interest is to develop superior specific hybrids, it may be more effective to search among all possible crosses between elite inbreds lines, including both good (positive) and poor (negative) general combiners. In view of the above results, due attention has to be given when selecting or rejecting parents in maize breeding programmes (Marame *et al*., 2009).

A significant and positive GCA effect for days to silking and days to tasseling was observed in P1 and P3 (Table 4). P8 showed negative GCA effects for both days to silking and taselling for these traits, indicating the potential advantage of inbred lines for development of early maturing hybrids. P5 and P7 showed negative significant GCA effects for time to tasseling. Aminu et al. (2014) reported similar results for these traits. For plant height, P1, P2 and P7 had positive and significant GCA effects of 0.92, 2.10 and 4.40, respectively. P3, P4, P5 and P6 contributed to shorter plant type in their crosses, and had a negative and significant GCA effect of -1.81, -0.87, -3.30 and -1.50 cm, respectively.

For number of ears per plant, all the inbred lines manifested significant GCA effects, imply that the inbred lines were developed based on GCA effects for number of ears per plant. This finding is in consistent with Malik *et al.* (2004), Aminu and Izge (2013) and Aminu *et al.* (2014).

For ASI (anthesis silking interval), P2 and P3 showed significant and positive GCA effects of 0.23 and 0.21, respectively (Table 4). For 100-kernel weight, P4, P5 and P8 showed significant and positive GCA effects of 0. 12, 0.68 and 0.38, in that order. Malik *et al.* (2004) reported significant and positive GCA in certain maize inbred lines. P2 and P5 showed positive and highly significant GCA effects for ear length, suggesting that these lines were good combiners for increased ear length. Mandefro and Habtamu (1999) and Bayissa *et al.* (2008) reported similar results for these traits.

For ear height, P3 and P4 showed GCA effects in a negative direction, implying the tendency of the lines to reduce ear height. Rodrigues and Chaves (2002) and Aminu *et al.* (2014) obtained similar results for ear height. In addition, for ear length, P3 and P4 showed negative GCA effects implying the tendency of lines to reduce ear length. Negative GCA effect is also obtained by Bayissa *et al.* (2008) for ear length in some maize inbred lines. For leaf senescence, P5, P6, P7 and P8 showed positive and significant GCA effect, indicating that these lines were good combiner for stay green. However, P1, P2 and P3 revealed

TABLE 3. Means of 8 subtropical maize germplasm and their crosses across 3 environments for grain yield, high-parent heterosis for grain yields and other plant parameters at Pantnagar, Dholi and Gorakhpur in India

Pedigree	Grain yield (kg ha^{-1})	Heterosis for yield (%)	Days to silk (days)	Plant height (cm)	Ear height (cm)	Ear plant^{-1}	Days to tassel	ASI	100 kernel weight (gm)	Ear diameter (cm)	Ear length (cm)	Leaf senescence
P1 x P2	1124.25	51.2	54.67	129.56	51.41	1.01	50.56	3.56	27.92	3.13	10.95	3.25
P1 x P3	2307.74	9.36	52.33	147.57	65.94	1.01	48.89	2.33	23.03	3.52	13.59	3.56
P1 x P4	722.29	51.2	50.33	147.41	54.02	1.01	47.56	2.22	28.61	3.43	12.88	1.95
P1 x P5	1035.22	51.2	51.67	144.32	58.55	1.02	47.56	3.11	25.95	3.62	11.09	2.58
P1 x P6	1399.45	65.14	53	160.93	69.97	1.02	49.89	2.67	26.28	3.2	11.6	3.58
P1 x P7	2684.56	2.39	51.67	163.05	67.72	1.01	47.56	3.56	28.93	3.43	13.18	2.6
P1 x P8	2711.55	16.34	50.67	156.63	64.54	1.02	46.56	3.89	25.52	3.59	14.16	2.92
P2 x P3	2041.56	47.71	53.67	142.43	52.16	1.02	49.89	3	25.56	2.88	12.34	2.26
P2 x P4	2423.75	30.28	51.67	137.87	50.27	1	47.89	3.11	22.6	3.71	12.33	2.91
P2 x P5	2508.3	30.28	52	142.38	48.79	1.01	47.22	3	25.92	3.88	13.97	3.89
P2 x P6	2189.04	30.28	51.67	126.75	48.46	1.01	47.89	3.22	27.26	3.43	12.12	2.91
P2 x P7	3296.1	4.58	51.33	138.98	53.9	1.04	47.22	3.67	24.61	3.72	13.37	2.6
P2 x P8	3006.51	12.85	52	141.58	47.72	1.03	48.22	3.56	24.57	3.72	13.47	2.92
P3 x P4	2599.12	4.58	51	150.32	48.67	1.01	47.22	4	29.05	4.36	13.4	2.91
P3 x P5	1691.27	56.43	50.33	137	45.47	1.02	46.56	4	26.18	3.78	11.55	3.57
P3 x P6	1062.21	82.57	55	123.7	44.89	1.02	51.56	389	27.09	3.68	11.87	2.59
P3 x P7	2680.08	30.28	50.33	162.17	62.61	1.01	46.56	3.22	28.57	3.91	12.48	3.25
P3 x P8	1893.18	40.74	53	139.33	52.24		49.22	2.89	27.92	3.45	12.4	3.56
P4 x P5	1759.19	58.17	52	141	55.6	1.03	47.89	3.33	29.38	3.85	13.32	2.6
P4 x P6	1498.38	79.08	51.67	146.23	64.72	1.01	47.22	2.89	22.31	3.84	13.54	3.56
P4 x P7	2040.66	47.71	51	149.96	58.66	1.02	47.22	2.89	26.34	4.17	12.58	3.89
P4 x P8	1618.88	51.2	50.67	149.27	52.25	1.02	46.56	2.89	27.88	4	12.25	3.89
P5 x P6	2103.6	30.28	50	164.34	57.27	1.02	46.22	2.78	27.19	3.71	13.16	3.65
P5 x P7	3034.39	16.34	52	160.62	61.29	1.01	48.22	2.89	27.56	3.81	14.12	3.56
P5 x P8	2507.4	30.28	51	158.08	65.68	0.81	46.89	3.44	29.56	4	12.51	3.9
P6 x P7	2913.9	47.71	50	165.98	56.67	1.01	45.89	2.67	25.89	3.91	12.32	3.65
P6 x P8	2096.43	12.85	49	145.15	53.68	1.03	45.89	2.33	29.46	3.43	13.69	3.23
P7 x P8	2448.05	64.14	49	137.56	58.38	1.04	44.56	2.67	25.19	4.26	14.17	3.89

TABLE 3. Contd.

Pedigree	Grain yield (kg ha^{-1})	Heterosis for yield (%)	Days to silk (days)	Plant height (cm)	Ear height (cm)	Ear plant^{-1}	Days to tassel	ASI	100 kernel weight (g)	Ear diameter (cm)	Ear length (cm)	Leaf senescence
Parents												
Pop3121/7	559.02	-	55	114.26	50.12	1.01	51.22	3.22	26.61	3.98	11.54	1.62
YHP P42-1	1226.77	-	52	165.12	51.53	1.01	47.22	3.56	27.61	5.22	13.47	1.62
Pop 3121/13	792.84	-	53.67	124.07	43.36	1	49.56	3.33	27.59	4.58	9.61	2.58
YHP P10	1389.59	-	54.33	119.01	44.11	1.01	50.56	2.78	27.59	2.91	8.89	2.58
Pop 3123	696.2	-	54.33	94.02	38.4	1.01	49.89	2.44	24.41	3.33	11.53	2.6
YHP P147	1630.58	-	54	112.57	49.15	1.01	49.89	2.44	26.05	3.42	9.54	2.58
YHP P42-9	554.99	-	56	117.2	45.51	1.02	52.22	3.22	26.92	3.1	9.26	2.58
Tarun 83	540.6	-	54.67	118.58	47.11	1.01	50.89	3.11	26.91	3.13	9.43	2.58
Mean	1882.99	51.13	140,97	53.83	1.01	98.22	3.11	26.68	3.72	12.28	2.97	
LSD (5%)	0.93	-	3.64	0.64	0.46	0.52	3.5	6.44	1.32	0.73	0.73	0.3

negative and significant GCA effect, suggesting that these lines were not good combiners for stay green. Similar results have also been reported by Lone (2006). P2 and P3 showed positive and significant GCA effects for cob diameter in desirable direction. This finding is supported by Lone (2006), who reported significant GCA effects for cob diameter in maize in India.

Results from this study indicate that in inbred lines developed at the Govind Ballabh Pant University of Agriculture and Technology, the SCA and GCA effects are quite important for all the characters studied, suggesting the importance of additive and non-additive gene actions in controlling these triats. Pixyley and Bjarnason (1991) conducted four diallel studies at CIMMYT involving tropical lines and obtained similar results for grain yield. They concluded that yield was controlled largely by additive gene action. In addition, Han *et al*. (1991) and Vasal and Srinivasan (1991) identified several superior hybrids in the experiment involving CIMMYT maize germplasm and reported that both specific combing ability (SCA) and general combining ability (GCA) effects were important for grain yield.

In the present study, crosses manifested considerable variation in SCA effects for different traits. For grain yield, P1 x P8 was the best specific combiner, followed by P5 x P7, P2 x P7, P3 x P4 and P2 x P8 crosses in that order. Therefore, these crosses could be selected for specific combining ability to improve grain yield. P7 and P8 manifested a high positive SCA effect with P2, implying that these two lines combine well with P2. Girma (1991) and Bayisa *et al*. (2008) reported on the significance of SCA effects and concluded that the predominance of non-additive genetic variance exists in yield. For plant height, P5x P6 was the tallest cross, while P2 x P6 was the shortest (Table 5). Thirteen crosses showed a positive and significant SCA effect, while six crosses manifested significant SCA effects in undesirable direction for ear height, indicating that the crosses had a good specific combination for shorter ear placement. Seventeen crosses showed positive and significant SCA effect; while three crosses revealed a significant SCA effects in undesirable direction for ear length (Table 5).

TABLE 4. General combining ability (GCA) effects of parental inbreds for different characters maize pooled over three environments

Parent	Days to 50% tasseling	Days to 50% silking	ASI	Plant height (cm)	Ear height (cm)	Ear plant^{-1}	Yield (kg ha^{-1})	1000 kernel weight (g)	Ear diameter (cm)	Ear length (cm)	Leaf senescence	Cob diameter	Leaf senescence
1 Pop3121/7	0.70**	0.52**	-0.02	0.92**	4.80**	0.01	-284.38**	0.14	-0.18	-0.30**	0.01	-0.18**	-0.30**
2 YHP P42-1	-0.07	0.18	0.23**	2.10**	-2.77**	0.02	209.61**	-0.64**	0.33	-0.31**	0.50**	0.33**	-0.31**
3 Pop 3121/13	0.50**	0.38**	0.21**	-1.81**	-2.18**	0.01	-108.61**	-0.01	0.15	-0.05**	-0.33**	0.15**	-0.05**
4 YHP P10	-0.13	-0.22	-0.11	-0.87**	-1.60**	0.01	-50.55**	0.12**	-0.05	-0.02	-0.24**	-0.05**	-0.02
5 Pop 3123	-0.37**	-0.15	-0.05	-3.30**	-1.50**	-0.02	-91.51**	0.68**	-0.11	0.24**	0.23**	-0.11**	0.24**
6 YHP P147	0.03	-0.08	-0.26**	-1.05**	0.55*	0.01	-42.27**	-0.58**	-0.07	0.14**	-0.31**	-0.07**	0.14**
7 YHP P42-9	-0.23*	-0.18	0.01	4.40**	2.28**	0.01	326.08**	-0.09**	-0.03	0.08**	0.06	-0.03*	0.08**
8 Tarun 83	-0.43**	-0.45**	-0.01	-0.4	0.42	-0.01	41.63**	0.38**	-0.04	0.21**	0.1	-0.04**	0.21**
SE (gi_i)	0.11	0.11	0.03	0.25	0.15	0.01	2.91	0.04	0.001	0.01	0.03	0.01	0.01

ASI = Anthesis silking interval. *, ** = Significant at the 0.05 and 0.01 probability levels, respectively

TABLE 5. Specific combining ability effect of F_1's for different characters maize pooled over three environments at at Pantnagar, Dholi and Gorakhpur in India

Cross	Days to 50% tasseling	Days to 50% silking	ASI	Plant height (cm)	Ear height (cm)	Ear plant $^{-1}$	Yield (kg ha^{-1})	Ear diameter (cm)	1000 kernel weight (g)	Ear length (cm)	Leaf senescence
1. P1 x P2	1.70	1.84	0.24	-14.44**	-4.44**	-0.01	-683.97**	-0.34**	1.76**	-1.83**	0.89**
2. P1 x P3	-0.53	-0.70	-0.96**	7.48**	9.49**	0.01	817.74**	-0.25**	-3.78**	1.64**	0.94**
3. P1 x P4	-1.23	-2.10	-0.76**	6.38**	-2.99*	-0.01	174.23**	0.13	1.67**	0.83**	-0.69**
4. P1 x P5	-1.00	-0.83	0.07	5.72*	1.43	0.01	-471.87**	-0.22*	-1.54**	-1.42**	-0.33**
5. P1 x P6	0.93	0.44	-0.16	20.09**	10.80**	0.01	-156.89**	-0.04	0.05	-0.37	0.77**
6. P1 x P7	-1.13	-0.80	0.46*	16.76**	6.82**	0.01	759.87**	0.09	2.21**	0.84**	-0.14
7. P1 x P8	-1.93	-1.53	0.81**	15.14**	5.49**	0.01	1071.31**	-0.61**	-1.68**	1.78**	0.05
8. P2 x P3	1.23	0.97	-0.54**	1.17	4.27**	0.01	57.56*	-0.49**	-0.47	-0.11	-0.35**
9. P2 x P4	-0.13	-0.43	-0.12	-4.34	0.81	0.01	381.70**	-0.12	-3.56**	-0.21	0.26**
10. P2 x P5	-0.57	-0.16	-0.28	2.60	-0.77	0.02	507.21**	-0.51**	-0.80*	0.97**	0.98**
11. P2 x P6	-0.30	-0.56	0.15	-15.27**	-3.15*	-0.02	138.71*	-0.27**	1.18**	-0.35	0.10
12. P2 x P7	-0.70	-0.80	0.33	-8.50**	0.56	-0.01	877.41**	-0.30**	-1.33**	0.53*	-0.14
13. P2 x P8	0.50	0.14	0.23	-1.09	-3.76**	0.01	872.28**	0.35**	-1.85**	0.59**	-0.27**
14. P3 x P4	-1.37	-1.30	0.80**	12.02**	-1.38	0.02	875.28**	-0.04	2.25**	1.69**	0.02
15. P3 x P5	-1.80	-2.03	0.74**	1.13	-4.68**	0.02	8.40	-0.08	-1.17**	-0.62**	-0.25**
16. P3 x P6	2.80**	2.57*	0.84**	-14.41**	-7.31**	-0.01	-669.90**	0.11	1.01**	0.23	0.51**
17. P3 x P7	-1.93	-2.00	-0.09	18.61**	8.68**	0.01	579.61**	-0.38**	2.00**	0.83**	-0.41**
18. P3 x P8	0.93	0.94	-0.42*	0.56	3.16*	0.02	77.17*	0.02	0.86*	0.35*	0.12
19. P4 x P5	0.17	0.24	0.38*	4.19	4.88**	0.01	18.26	0.29**	1.90*	1.06**	0.37**
20. P4 x P6	-0.90	-0.16	0.15	7.18**	7.95**	0.01	-291.79**	0.24**	-3.91**	1.81**	-0.50**
21. P4 x P7	-0.63	-0.73	-0.12	5.46*	4.16**	-0.01	-117.87*	0.54**	-0.37	0.48*	0.53**
22. P4 x P8	-1.10	-0.80	-0.10	9.57**	-0.40	0.02	-255.20**	0.38**	0.70	0.11	0.73**
23. P5 x P6	-1.67	-1.90	-0.02	27.72**	4.39**	0.02	354.40**	0.17	0.41	0.97**	0.21*
24. P5 x P7	0.60	0.20	-0.17	18.55**	6.68**	0.01	916.84**	0.24**	0.29	1.55**	0.27**
25. P5 x P8	-0.53	-0.53	0.40*	20.80**	12.93**	-0.17	674.30**	0.44**	1.81**	-0.10	0.47**
28. P6 x P7	-2.13*	-1.86	-0.18	21.67**	0.02	-0.01	647.10**	0.29**	-0.12	0.30	0.37**
27. P6 x P8	-1.93	-2.60*	-0.50**	5.63*	-1.14	0.02	214.08**	-0.19*	2.98**	1.63**	-0.09
28. P7 x P8	-3.00**	-2.50*	-0.44*	-7.41**	-1.15	0.04*	197.35**	0.62**	-1.78**	1.73**	0.63**
SE (s_i)	1.03	1.07	0.18	2.33	1.36	0.01	27.21	0.09	0.38	0.22	0.09

ASI= Anthesis silking interval. *, ** = Significant at the 0.05 and 0.01 probability levels, respectively, SE = .Standard Error

Thus, P4 x P6 (1.81) and P1 x P2 (-1.83) were the best and worst specific combiners for ear length.

For days to silking and anthesis, P3 x P6 was the latest and crosses involving P6 x P8 and P7 x P8 were the earliest for days to silking and tasseling, respectively. Among crosses, P3 x P6 had highest ASI, where as cross P1x P3 had the lowest negative and significant effect for ASI; indicating the cross has a good specific combination for earlier ASI.

For 1000-kernel weight, 11 crosses showed positive and significant SCA effects, but 10 crosses showed negative SCA effects. Similarly, for cob diameter, 9 crosses displayed positive and significant SCA effects yet 10 crosses showed negative SCA effects. For leaf senescence, 50% of the crosses manifested positive and significant SCA effects (Table 5).

CONCLUSION

In the present study, as the results revealed that many inbred lines themselves have high GCA effects. Those showing high SCA effects combine well with other inbreds. The findings of this study have showed the importance of additive and non additive gene action in grain yield. Lines with good GCA and SCA effects for grain yield were identified. The information from this experiment will be useful for maize breeders in India. Hence, an effective breeding strategy for maize could, therefore, be based on inbred lines derived hybrids or multiple crosses using genetically diverse maize inbred lines. In general, the findings of this study will be valuable for researchers who intend to develop high yielding varieties.

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