Original Research Article

Combining Ability Analysis for Grain Yield and Yield Attributing Traits in Line×Tester Crosses of Maize Across the Locations.

ABSTRACT

Combining ability of inbred lines is the ultimate factor determining future usefulness of the lines for hybrid development while, an idea about the nature of gene action controlling the yield and yield contributing characters is important for development of fruitful breeding programme. Owing to this, the present study was carried out to investigate the GCA and SCA effect of parental lines and hybrids respectively, and to deduce the type of gene action regulating the grain yield and its components. The 30 single cross hybrids were generated by crossing 6 lines with 5 testers in line x tester mating system and evaluated along with four checks at three locations for the estimation of combining ability effects. Significant differences were observed among the inbred lines, testers, hybrids and parents vs. hybrids for most of the studied traits. The non-additive gene action was predominant for all studied traits except plant height. PFSR 145 found to be good general combiner for traits such days to 50% tasselling, days to 50% silking, days to maturity, plant height and ear height. GP 329 is best general combiner for ear girth, number of kernel per ear, number of kernels per row, 100 kernel weight and grain yield. These parents could be used in future breeding programme for the accumulation of favourable genes and thereby improve maize yield with desirable traits. Hybrid GP 82×GP 83 found to be the best specific combiner for days to 50% tasseling, days to 50% silking, days to maturity, number of kernels per ear and grain yield. The hybrid GP 82×GP 83 can be further tested extensively for the development of potential early maturing hybrids.

*Key words***:** *Combining Ability, GCA, SCA, Maize*

1. INTRODUCTION

Maize (*Zea mays* L. 2n = 20) belonging to tribe *Maydeae,* of the grass family, *Poaceae*. Maize is the third most important crop in the world as well as in India after wheat and rice. The crop is cultivated in about 170 countries in an area of 193.7 Mha with production of 1147.7 Mt and an average productivity of 5754.7 kg/ha, which accounts for 37 per cent of total global grain production [1]. In India, maize occupies an area of 9.26 Mha with 16.72 MT production and productivity of 3024 kg/ha. In Telangana, the crop shares 10.22 per cent of the area (2 lakh ha) under cultivation with the production of 6777 kg/ha [2].

Globally, maize is an important crop because of its diverse uses mainly as food (17%), feed (61%) and raw material for industrial uses (22%). It is estimated that the demand for maize will continue to increase in view of increasing demand in poultry and livestock sectors in the country and growing non-vegetarian population and changing food habits [3]. Maize is used as raw material in many important industries viz., starch, oil, alcoholic beverages, food sweeteners, pharmaceuticals, cosmetics, textile, paper, film, tyre, food processing, packing and bio-fuel etc. for developing hundreds of industrial products. It also plays a key role in the Indian economy by contributing a significant share in global agricultural exports and imports. In 2019, according to the ITC Trade Map database the total export and import and export volume of maize in India was 312,389 and 379,000 metric tons, respectively.

Owing to its wide range of plasticity, maize is adaptable to diverse environments and offers tremendous scope for expansion to new areas and environments compared to many other crops. Over the years, maize has registered impressive production gains both at global and national levels and this could be attributed largely to successful adoption of single cross hybrid technology. However, to match the growing requirement of consumers across the globe, there is an urgent need to further improve the productivity level especially in developing nations including India. The production and productivity of maize enhance by using improved hybrid maize varieties accompanied with appropriate agronomic practices.

Inbred lines have an essence importance for hybrid development in maize. Combining ability analysis is remarkably important in allogamous species including maize as it aids in identification of potential parents which assures the development of promising hybrids and synthetics. The utility of inbred line in the development of maize hybrid can be assessed by two factors, the features of inbred line itself regarding yield potential, pollen producing ability, resistance to diseases, etc. and its behaviour in hybrid combinations [4]. In recent years, the combining ability concept has become increasingly important not only in maize but in other crops as well.

An impressive breeding programme enhances the chances of producing promising varieties of a crop. However, the formulation of fruitful breeding programme requires the details of nature of gene actions regulating the yield and its component traits which helps the breeder to evolve new commercial crop varieties. Combining ability studies sounds well since they aid in selection of parents effectively and thus enhances the hybrid performance. It also assists to have an idea regarding the nature of gene action for a specific trait. This information is also useful to breeder for selection of diverse parents and hybrid combinations. Owing to this, the present investigation was carried out to dictate the general combining ability of parents for yield and its components and to identify the best performing hybrids on the basis of specific combining ability.

2. MATERIAL AND METHODOLOGY

2.1 Description of Study Area

The present investigation was carried out during two crop seasons *kharif*, 2022 and *rabi*, 2022 on the experimental farm of Maize Research Centre, Rajendranagar, Hyderabad. The study area located at latitude of 17^{o} 20' N, longitude of 78^{o} 25' E and an altitude of 545 m above MSL. The area receives an average rainfall of 99.08 millimetres (3.9 inches) and has 107.27 rainy days (29.39% of the time) annually.

2.2. Generation and Evaluation of Experimental Material

The 6 inbred lines were designated as a female and 5 testers designated as a male were crossed in Line × Tester mating system during *kharif*, 2022. The experimental units consisted of six rows of 4 m length plots, with a spacing of 0.6 m × 0.2 m. Three staggered sowings of the male testers were undertaken at an interval of 4 days to ensure synchronization of flowering with female lines and to produce adequate crossed seeds.

A panel of 30 experimental single-cross hybrids were evaluated for eleven quantitative traits along with 11 parents and 4 checks (NK 6240, Hitech 5160, Hitech 5106 and Bio 9544) across three locations (Rajendranagar, Karimnagar and Madhira) during *rabi*, 2022-23. The seed material was sown in a Randomized Block Design with three replications following a spacing of 0.6 m × 0.2 m. All the recommended package of practices for specific site were followed to maintain proper crop stand.

2.3. Data Collection

The data was recorded on five randomly selected plants in each entry for parameters such as plant height (cm), ear height (cm), ear length (cm), ear girth (cm), number of kernel rows per ear, number of kernels per row, 100 seed weight (g) whereas, days to 50 % tasseling, days to 50 % silking, days to maturity and grain yield were recorded on a plot basis.

2.4. Data analysis

The pooled combining ability analysis and the testing of the significance of maize genotypes were carried out according to the procedure given by Kempthorne [5]. The additive model used to estimate the GCA and SCA effects of the ijk observations as follow:

$$X_{ij} = \mu + g_i + g_j + s_{ij} + e_{ijk}$$

Where,

μ= population mean
g_i= GCA effect of the i^{th} female parent
g_j = GCA effect of the j^{th} male parent
s_{ij} = SCA effect of the ij^{th} combination
e_{ijk} = error associated with the observation X_{ijk}
i = number of female parents
j = number of male parents
k = number of replications

3. RESULT AND DISCUSSION

3.1 Pooled Analysis of Variance for Combining Ability Using Line X Tester Mating System

The pooled analysis of variance for combining ability exhibited the presence of significant differences over the tested locations and among the genotypes (Table 1). The source of variation partitioned into parents, hybrids and parents vs. hybrids and revealed the significant differences among the inbred lines, testers, hybrids and parents vs. hybrids for most of the studied traits over three locations. Similar results were reported by Kanoosh [6] and Debesa Gobu [7].

3.2 Estimation of Components of Variance for Combining Ability

The components of variance for combining ability analysis (Table 1) showed that the ratio of GCA to SCA variance was less than unity for all the traits except plant height indicating the presence of non-additive gene action, hence heterosis breeding will be more effective in improvement of such characters. These results were in accordance with Talukder *et al.*[8], Gazala *et al.* [9], Kanoosh [10], Suyadi *et al.* [10] and Kumar *et al.* [11].

Table 1. Pooled analysis of variance for combining ability of parents and crosses over three locations.

Source of variation	Degree of freedom	Mean sum of squares					
		Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm)	Ear height (cm)	Ear length (cm)
Location	2	28.18**	21.39**	61.22**	595.04*	19.68	7.63**
Parents	10	100.31**	100.71**	131.54**	78.72	125.94**	7.81**
Lines (Females)	5	87.97**	95.69**	41.44**	70.84	143.38**	12.46**
Testers (Males)	4	139.05**	132.13**	275.36**	61.69	29.54	3.94
Lines vs. Testers	1	7.03	0.14	6.79	186.20	424.32**	0.03
Crosses	29	62.21**	63.17**	175.54**	169.11	81.61**	5.38**
Parent vs. crosses	1	270.95**	267.04**	398.20**	93749.79**	10153.25**	2918.03**
Location × Parents	20	2.63	2.61	31.90**	128.77	39.65	0.73
Location × Lines	10	3.36	3.64*	37.76**	164.05	41.91	0.63
Location × Testers	8	2.27	1.75	30.89**	86.02	44.93	1.01
Location × PAR(Lines vs. Testers)	2	0.48	0.85	6.70	123.34	7.21	0.12
Location × Crosses	58	4.70**	4.19**	14.33**	113.66	53.09*	1.52
Location × Parent vs. crosses	2	4.19*	2.28	140.41**	102.16	29.99	1.91
Error	120	1.91	1.80	6.76	129.14	34.20	2.28
σ^2 GCA/σ^2 SCA	-	0.17	0.15	0.13	2.98	0.42	0.04

**Significance at 5% probability, **significance at 1% probability*

Table 1. (cont.)

Source of variation	Degree of freedom	Mean sum of squares				
		Ear girth (cm)	Number of Kernel per ear	Number of kernels per row	100 kernel weight (g)	Grain yield (kg ha^{-1})
Location	2	0.14	1847.78	33.84**	41.26**	6823607.13**
Parents	10	1.90	2468.76**	13.94**	43.98**	400482.19
Lines (Females)	5	1.74	4276.00**	21.64**	60.23**	648138.38
Testers (Males)	4	2.50	826.85	6.01	33.42**	161386.26
Lines vs. Testers	1	0.27	0.24	7.17	5.01	118584.94
Crosses	29	1.50	12296.10**	17.37**	19.63**	2534245.60**
Parent vs. crosses	1	685.09**	2996665.70**	5264.61**	3186.20**	2544948120.87**
Location × Parents	20	1.17	440.51	5.70	8.70*	275712.70
Location × Lines	10	1.20	474.79	3.42	8.88*	230516.97
Location × Testers	8	1.24	467.66	7.49	9.80*	384862.13
Location × PAR (Lines vs.Testers)	2	0.76	160.51	9.94*	3.42	65093.56
Location × Crosses	58	0.58	1068.37	6.06	13.91**	1444297.59**
Location × Parent vs. crosses	2	0.07	1116.52	38.26**	4.33	1829624.35**
Error	120	1.04	932.17	4.38	4.69	333618.34
σ^2 GCA/σ^2 SCA	-	0.49	0.43	0.20	0.07	0.10

**Significance at 5% probability, **significance at 1% probability*

3.3 Mean Performance of Parents and Single Crosses

Mean performance of 30 single crosses along with 6 inbred lines, four testers and four checks for eleven quantitative traits was recorded over three locations and presented in Table 2. The inbred lines recorded a range for grain yield varied from 3972.5 kg ha^{-1} (GP 329) to 4885.9 kg ha^{-1} (PFSR 204) and the testers exhibited a range from 4434.7 kg ha^{-1} (GP 69) to 4833.3 kg ha^{-1} (GP 36). The lowest value for grain yield was recorded for PFSR 145×GP 83 (10361.25 kg ha^{-1}) and the highest value was observed for GP 239×GP 83 (12772.2 kg ha^{-1}). Thirteen hybrids (PFSR 393×GP 83, PFSR 393×GP 86, PFSR 393×GP 107, PFSR 204× GP 107, GP 329×GP 69, GP 329×GP 83, GP 329×GP 86, GP 329×GP 107, GP 327× GP 36, GP 327× GP 107, PFSR 145×GP 69, PFSR 145×GP 86 and GP 82×GP 83) recorded the higher grain yield than the best check Bio 9544 (12061.0 kg ha^{-1}). Therefore, these high performing crosses than the standard check indicates the possibility of obtaining better commercial variety and thereby enhance the production and productivity of maize. These results are in accordance with the earlier findings of Meena *et al.* [12], Sserumaga *et al.* [13], Meseka *et al.* [14], Shrestha *et al.* [15] and Rezende *et al.* [16].

Days to 50% tasseling for inbred lines ranged from 47 days (PFSR 204) to 55 days (GP 82) and for testers 47 days (GP 36) to 58 days (GP 69). Hybrids recorded mean value of 54.0 days for days to 50% tasseling. PFSR 393×GP 36 (47 days) were found to be earliest and GP 329×GP 86 (59 days) was reported to be late among all hybrids in 50% tasseling. Days to 50% silking in the inbred lines ranged from 50 days (GP 329, PFSR 393 and PFSR 204) to 58 days (GP 82) and for the testers, 49 days (GP 36) to 60 days (GP 69) whereas, the hybrids showed the range for days to 50% silking from 50 days (PFSR 393×GP 36, PFSR 393×GP 107, PFSR 204×GP 36, GP 329×GP 83 and PFSR 145×GP 86) to 60 days (PFSR 393×GP 86, PFSR 204×GP 69, PFSR 204×GP 86, GP 329×GP 86, GP 327×GP 36 and GP 82×GP 36) with the mean value of 56.0 days. Early maturity is a desirable trait to overcome the problem of biotic and abiotic stresses. Days to maturity for the inbred lines ranged from 87 days (PFSR 204 and PFSR 393) to 98 days (GP 327) whereas, the testers showed a range of 86 days (GP 36) to 106 days (GP 69). Hybrids exhibited a range from 86 days (PFSR 393×GP 36 and PFSR 204× GP 36) to 107 days (GP 327× GP 36) with the mean value of 98 days.

For plant height, the inbred lines showed a range of 129.4 cm (GP 329) to 138.3 cm (PFSR 145) and for testers, the range was from 127.1 cm (GP 86) to 134.7 cm (GP 107). The plant height in hybrids ranged from 164.1 cm (PFSR 145×GP 83) to 185.0 cm (PFSR 393×GP 86) and showed the mean value of 176.4 cm. The inbred lines showed the mean value for ear height was ranged from 54.9 cm (GP 82) to 69.2 cm (PFSR 145) and the value ranged between 65.8 cm (GP 69) and 71.6 cm (GP 107) for testers. Hybrids had the mean value of 79.5 cm and exhibited the ear height ranged from 69.7 cm (GP 82×GP 86) to 85.4 cm (PFSR 204× GP 36). The inbred lines showed the ear length in the range of 11.0 cm (GP 329) to 14.5 cm (PFSR 204) and for tester the value ranged from 11.0 cm (GP 36) to 13.4 cm (GP 107). The hybrids exhibited the ear length ranged from 18.6 cm (PFSR 145×GP 83) to 21.7 cm (GP 329×GP 107) with the mean of 20.4 cm. For ear girth, inbred lines exhibited a range of 10.3 cm (PFSR 145) to 11.8 cm (GP 82) and for testers it was ranged from 10.4 cm (GP 69) to 11.9 cm (GP 36). The lowest ear girth was recorded by the hybrid PFSR 204× GP 83 (13.7 cm) whereas, the highest ear girth was observed for by GP 329×GP 69 (15.8 cm). Hybrids reported the mean value of 15.0 cm for ear girth.

Number of kernel per ear among inbred lines ranged from 183 (GP 329) to 264 (PFSR 145) while the testers exhibited a range from 215 (GP 86) to 245 (GP 36). The lowest number of kernels per ear was recorded by the hybrid PFSR 204 × GP 86 (353) and the highest value for the trait was recorded for GP 329×GP 86 (613). Hybrids showed the mean value of 469.7 for number of kernels per ear. Inbred lines showed a range of 22 (GP 329, GP 327 and GP 82) to 26 (PFSR 393 and PFSR 145) kernels per row. It ranged from 21 (GP 107) to 24 kernels (GP 36) for testers. The lowest value for number of kernels per row was observed for hybrid PFSR 145×GP 83 (30) whereas, the highest value was recorded for GP 329×GP 86 (37) and mean value recorded for hybrids was 33.4. The inbred lines showed a range of 18.9 g (GP 329) to 29.9 g (PFSR 145) for 100 kernel weight and the testers exhibited the range from 21.3 g (GP 69) to 28.7 g (GP 36). 100 kernel weight was found lowest for the hybrid GP329×GP 36 (30.0g) and highest value recorded for PFSR 393×GP 83 (38.2 g) and hybrids showed the mean of 32.8g for 100 grain weight.

Table 2. Mean performance of 45 genotypes for eleven quantitative traits across three locations.

S. No.	Genotypes	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear girth (cm)	Number of Kernel per ear	Number of kernels per row	100-kernel weight (g)	Grain-yield ((kg ha^{-1})
	Lines											
1	PFSR 393	48	50	87	132.0	59.8	12.4	11.4	228	26	28.7	4667.3
2	PFSR 204	47	50	87	136.5	64.7	14.5	11.4	219	23	26.2	4885.9
3	GP 329	48	50	88	129.4	64.8	11.0	11.1	183	22	18.9	3972.5
4	GP 327	54	56	98	135.7	62.8	13.6	10.7	232	22	25.8	4828.5
5	PFSR 145	52	54	95	138.3	69.2	11.6	10.3	264	26	29.9	4637.2
6	GP 82	55	58	97	131.3	54.9	12.1	11.8	241	22	23.7	4509.8
Range	**Minimum**	47	50	87	129.4	54.9	11.0	10.3	183	22	18.9	3972.5
	Maximum	55	58	98	138.3	69.2	14.5	11.8	264	26	29.9	4885.9
	Testers											
1	GP 36	47	49	86	132.4	67.6	11.0	11.9	245	24	28.7	4833.3
2	GP 69	58	60	106	127.6	65.8	13.1	10.4	222	22	21.3	4434.7
3	GP 83	53	56	98	130.7	66.8	12.4	11.8	226	23	27.2	4813.9
4	GP 86	57	59	94	127.1	67.3	12.9	11.2	215	23	23.4	4660.4
5	GP 107	48	50	89	134.7	71.6	13.4	10.9	229	21	25.7	4601.0
Range	**Minimum**	47	49	86	127.1	65.8	11.0	10.4	215	21	21.3	4434.7
	Maximum	58	60	106	134.7	71.6	13.4	11.9	245	24	28.7	4833.3
	Hybrids											
1	PFSR 393×GP 36	47	50	86	174.7	81.0	19.8	14.7	451	31	32.3	11510.4
2	PFSR 393×GP 69	52	54	103	175.5	77.8	19.5	15.3	463	35	30.9	11736.2
3	PFSR 393×GP 83	57	59	102	168.2	80.2	21.1	15.5	534	36	38.2	12173
4	PFSR 393×GP 86	58	60	103	185.0	85.1	21.1	14.7	497	35	33.9	12258.9
5	PFSR 393×GP 107	48	50	87	178.7	79.8	20.7	15.3	436	31	30.4	12651.7
6	PFSR 204× GP 36	48	50	86	182.7	85.4	20.0	14.6	458	35	32.2	11574.7
7	PFSR 204× GP 69	57	60	104	171.5	79.0	19.2	14.5	437	33	30.8	11638.8
8	PFSR 204× GP 83	57	59	102	168.6	79.9	20.8	13.7	451	31	31.2	10917.2
9	PFSR 204× GP 86	58	60	101	177.2	81.2	20.3	14.9	353	35	30.2	11939.3
10	PFSR 204× GP 107	55	57	100	183.3	82.8	21.1	14.4	454	33	35.5	12479.1
11	GP 329×GP 36	54	57	98	181.5	80.6	19.1	15.2	439	32	30	10802.9
12	GP 329×GP 69	57	59	96	177.5	81.6	20.5	15.8	536	36	34.2	12421.6
13	GP 329×GP 83	48	50	87	177.4	78.6	21.3	15.1	529	34	36.2	12772.2

14	GP 329×GP 86	59	60	100	180.3	76.6	21.2	15.7	613	37	36.5	12693.4
15	GP 329×GP 107	53	56	96	180.8	81.4	21.7	15.1	541	35	34.9	12579.0
16	GP 327×GP 36	58	60	107	182.3	82.8	21.3	15	471	34	32.2	12259.2
17	GP 327×GP 69	57	59	98	178.9	79.0	20.6	13.8	454	33	32.4	12024.3
18	GP 327× GP 83	54	57	95	170.0	81.4	19.2	15.2	435	33	30.9	11344.1
19	GP 327× GP 86	55	57	96	176.3	80.9	20.1	15	461	33	32.7	11913.5
20	GP 327× GP 107	55	57	100	177.2	83.0	21.3	14.8	463	35	34.3	12108.5
21	PFSR 145×GP 36	55	57	96	178.5	76.7	20.9	15.3	467	33	33	11928.9
22	PFSR 145×GP 69	55	58	97	173.9	78.6	20.6	15.3	423	33	35	12697.4
23	PFSR 145×GP 83	57	59	99	164.1	75.6	18.6	14.2	420	30	30.1	10361.3
24	PFSR 145×GP 86	48	50	88	171.0	75.4	21.3	14.7	466	35	35.4	12164.4
25	PFSR 145×GP 107	54	57	100	177.3	74.2	20.1	15.1	436	32	32	11764.5
26	GP 82×GP 36	58	60	99	177.5	78.2	21.0	15.1	470	33	32.4	11603.0
27	GP 82×GP 69	54	55	102	167.2	72.0	20.7	15.3	452	32	33.4	11642.6
28	GP 82×GP 83	49	52	91	182.2	84.6	20.4	15.4	555	34	33.1	12711.8
29	GP 82×GP 86	57	59	104	172.1	69.7	19.9	14.5	448	32	31.4	10714.8
30	GP 82×GP 107	54	57	103	180.8	83.2	20.2	15.3	488	33	31.6	11063.2
31	NK 6240	54	56	102	172.7	73.6	19.9	14.6	484	33	30.3	11501.7
32	Hi-Tech-5160	56	58	101	174.2	84.9	20.4	14.9	446	34	33.5	11572.1
33	Hi-Tech-5106	53	55	99	176.7	76.0	19.6	15.2	474	30	30.1	11159.8
34	Bio 9544	54	56	98	181.9	80.8	20.6	15.1	465	33	33.1	12061
Range	**Minimum**	47	50	86	164.1	69.7	18.6	13.7	353	30	30	10361.3
	Maximum	59	60	107	185.0	85.4	21.7	15.8	613	37	38.2	12772.2
	Mean	54.3	56.5	97.8	176.4	79.5	20.4	15.0	469.7	33.4	32.8	11845.4
	CV	3.0	2.0	2.0	4.6	6.5	5.1	4.2	8.0	6.0	7.3	7.3
	SEM	1.0	1.0	1.0	4.4	2.8	0.5	0.3	18.0	1.0	1.3	425.4
	CD@ 5%	2.0	1.0	3.0	12.5	8.1	1.5	0.9	50.0	3.0	3.6	1,197.8

***CV-** Coefficient of Variation**, SEM-** Standard Error Mean and **CD-** Critical Difference*

3.4 General Combining Ability (GCA) Effects

The details of GCA effects of 6 lines and 5 testers for all the studied traits over three locations are presented in the Table 3. Negative GCA effects are considered as desirable for days to 50% tasseling, since they are found to be associated with earliness. GCA effects of inbred lines ranged from -2.31 (PFSR 393) to 1.25 (GP 327). Among six inbred lines, two inbred lines PFSR 393 (-2.31) PFSR 145 (-0.77) exhibited significant negative GCA effect for days to 50% tasseling. Testers showed the GCA effects range from -1.52 (GP 69) to 0.97 (GP 83, GP 86 and GP 107) and two testers exhibited negative significant GCA *viz*., GP 36 (-1.38) and GP 107 (-1.52). Similar results were reported by Hoque *et al.* [17], Talukder *et al.* [8], Gazala *et al.* [9], Begum *et al.* [18] and Abdulazeez *et al.* [19]. Lines for days to 50% silking showed the GCA effect in the range between -2.33 (PFSR 393) to 1.23 (GP 327) and for tester it was ranged from -1.36 (GP 36 and GP 107) to 1.02 (GP 83). Significant negative GCA effect for the trait was exhibited by two lines PFSR 393 (-2.33) and PFSR 145 (-0.80) whereas, two testers also found to have significant negative GCA effect GP 36 (-1.36) and GP 107 (-1.36). These results were in accordance with the findings of Hoque *et al.* [17], Talukder *et al.*[8], Gazala *et al.* [9], Begum *et al.* [18] and Abdulazeez *et al.* [19]. GCA effect of lines for days to maturity ranged from -2.48 (PFSR 145) to 3.41 (GP 82) and for testers the values were in the range of -2.83 (GP 36) to 2.41 (GP 69). Two lines PFSR 393 (-1.78), PFSR 145 (-2.48) and two testers GP 36 (-2.83), GP 107 (-1.081) showed a significant negative GCA effect for days to maturity indicating that they were the good general combiners for early maturity trait. Similar results were reported by Matin *et al.* [20], Talukder *et al.* [8], Hoque *et al.* [17] and Zeleke *et al.* [21].

The lines showed GCA effects range from -3.44 (PFSR 145) to 3.1 (GP 329) whereas the range for testers was -4.63 (GP 83) to 3.28 (GP 107). Out of six inbred lines, one inbred line PFSR 145 (-3.44) exhibited significant negative GCA effect. On the other hand, tester GP 83 (-4.63) also exhibited significant negative GCA effect for plant height. Negative GCA effect of inbred lines for plant height is considered as desirable in order to develop short stature hybrids by using such lines. The current findings were in consonance with the results of Hoque *et al.* [17], Matin *et al.* [20], Owusu *et al.*[22] , Begum *et al.* [18] and Abdulazeez *et al.* [19]. The GCA effect of lines for ear height ranged from -3.44 (PFSR 145) to 2.09 (PFSR 204) and for testers these values ranged from -1.54 (GP 69) to 1.24 (GP 36). Line PFSR 145 (-3.44) exhibited significant negative GCA effect for ear height while, testers GP 69 (-1.54) and GP 86 (-1.37) showed negative GCA for ear height. Hoque *et al.* [17], Owusu *et al* [22], Begum *et al.* [18] and Zeleke *et al.* [21] reported similar results for ear height.

Positive GCA effect for ear length is considered desirable since it influences the grain yield directly. The trait ear length showed the GCA effects range from -0.30 (GP 82) to 0.50 (GP 329) for lines and from -0.34 (GP 69) to 0.38 (GP 86) for testers. Two lines PFSR 393 (0.10) and GP 329 (0.50) exhibited positive GCA effect for ear length. Similarly, two testers GP 86 (0.38) and GP 107 (0.28) also exhibited positive GCA effect for ear length. Begum *et al.* [18] also reported similar results for ear length. Ear girth showed the GCA effects ranged from -0.52 (PFSR 204) to 0.43 (GP 329) for lines. For testers the GCA values ranged from -0.10 (GP 83) to 0.06 (GP 107). The line GP 329 (0.43) exhibited the significant and positive GCA effect for ear girth. On the other hand, three testers GP 36 (0.03), GP 69 (0.04) and GP 107 (0.06) showed positive GCA effect for the trait. Hoque *et al.* [17] reported the similar results for ear girth.

The GCA effect of number of kernel per ear for lines ranged from -32.11 (PFSR 145) to 56.74 (GP 329). The line GP 329 (56.73) reported the significant positive GCA effect for number of kernel per ear. The trait showed the range between -16.51 (GP 36) to 21.88 (GP 83) for testers. Out of five testers, GP 83 (21.88) and GP 107 (10.94) reported positive and significant GCA effect for number of kernel per ear. Similar results were reported by Gazala *et al.* [9]. Among the lines, lowest GCA effect for number of kernel per row was shown by GP 82 (-0.75) while, highest value was recorded for GP 329 (1.43). The line GP 329 (1.43) showed the significant and positive GCA effect for number of kernel per row. Among the testers, the lowest and highest GCA effects were reported by GP 83 (-0.62) and GP 86 (1.12), respectively. The tester GP 86 (1.12) exhibited the positive and significant GCA for the trait. These results were in line with Ambikabathy *et al.* [23]. 100 grain weight showed the GCA effect for lines in the range of -0.49 (GP 82) to 1.38 (GP 329). For testers, the GCA effects ranged from -0.90 (GP 36) to 0.40 (GP 86). Among six lines, one line GP 329 (1.38) exhibited the significant and positive GCA effect for 100 grain weight whereas, all the testers except GP 36 showed positive GCA effect for 100 grain weight. These results were in accordance with Rajitha *et al.* [24], Attia *et al.* [25] and Ambikabathy *et al.* [23].

Among all lines, the lowest GCA value for grain yield was reported by GP 82 (-334.59) and the highest value exhibited by GP 329 (372.16). The GCA effect of testers for grain yield ranged from -268.47 (GP 36) to 225.99 (GP 107). The line GP 329 (394.73) and tester GP 107 (225.99) recorded significant and positive GCA effect for grain yield. These findings were in agreement with Begum *et al.*[18], Karim *et al.* [26], Murtadha *et al.* [27], Ambikabathy *et al.* [23], Elmyhun *et al.* [28], Kamara *et al.* [29], Zeleke *et al.* [21], Kumar *et al.* [11], Olayiwola *et al.* [30] and Suyadi *et al.* [10].

3.5 Specific Combining Ability (SCA) Effects

The SCA effects of 30 hybrids evaluated at three locations for eleven quantitative traits are presented in Table 4. The SCA effect of hybrids for days to 50% tasseling ranged from -6.47 (PFSR 145×GP 86) to 4.39 (PFSR 393×GP 86) while, days to 50% silking showed the SCA ranged from -6.72 (PFSR 145×GP 86) to 4.63 (PFSR 393×GP 86). Out of 30 hybrids, 9 hybrids (PFSR 393×GP 36, PFSR 393×GP 107, PFSR 204× GP 36, GP 329×GP 83, GP 327× GP 83, GP 327× GP 86, PFSR 145×GP 86, GP 82×GP 69 and GP 82×GP 83) exhibited significant and negative SCA for the days to 50% tasseling and days to 50% silking. These results were in accordance with Owusu *et al.* [22], Begum *et al.* [18] and Karim *et al.* [26]. The SCA effect for days to maturity ranged from -9.73 (PFSR 204× GP 36) to 10.91 (GP 327× GP 36). Ten hybrids (PFSR 393×GP 36, PFSR 393×GP 107, PFSR 204× GP 36, GP 329×GP 69, GP 329×GP 83, GP 327×GP 69, GP 327× GP 83, GP 327× GP 86, PFSR 145×GP 86 and GP 82×GP 83) exhibited the significant and negative SCA effect for days to maturity. Similar results were reported by Hoque *et al.* [17].

Plant height exhibited the SCA value in the range of -6.44 (GP 82×GP 69) to 10.92 (GP 82×GP 83). None of the hybrids showed significant negative SCA effect for plant height. These results are perfectly parallel with those of Begum *et al.* [18] for plant height. The lowest SCA effect for ear height was observed for the hybrid GP 82×GP 86 (-6.43) while, the highest value was recorded for GP 82×GP 83 (6.55). Only one (GP 82×GP 86) out of 30 hybrids recorded the significant and negative SCA value for ear height. These results are in lined with the findings of Karim *et al.* [26]. The SCA effect of ear length for hybrids ranged from -1.77 (GP 329×GP 36) to 1.40 (PFSR 145×GP 36). The hybrid PFSR 145×GP 36 showed the significant and positive SCA effect for ear length. These results were in agreement with Aslam *et al.* [31] and Begum *et al.* [18]. The lowest SCA effect for ear girth was reported by GP 327×GP 69 (-0.98) whereas, the highest value was observed for GP 327× GP 83 (0.53). None of the hybrid exhibited significant and positive SCA for ear girth.

The SCA effect for number of kernel per ear ranged from -78.52 (GP 329×GP 36) to 62.15 (GP 82×GP 83). Significant and positive SCA effects for number of kernel per ear were observed in six hybrids (PFSR 393×GP 83, PFSR 204× GP 36, GP 329×GP 86, GP 329×GP 107, PFSR 145×GP 36 and GP 82×GP 83). The character number of kernel per row had SCA effect ranged from -2.59 (PFSR 393×GP 107) to 2.52 (PFSR 393×GP 83). Out of 30 hybrids, three hybrids *viz*., PFSR 393 ×GP 69, PFSR 393×GP 83 and PFSR 204×GP 36 exhibited significant and positive SCA effect for the trait number of kernel per row. The results were in lined with the findings of Hoque *et al.* [17], Aslam *et al.* [31] and Begum *et al.* [19]. Out of 30, three hybrids (PFSR 393×GP 83, PFSR 204× GP 107 and PFSR 145×GP 69) reported positive and significant SCA effect for the trait 100 grain weight. The SCA effect of the hybrids for 100 grain weight ranged from -2.92 (PFSR 145×GP 83) to 3.65 (PFSR 393×GP 83). These results are in agreement with the findings of Aslam *et al.* [31].

The lowest SCA effects for grain yield was exhibited by a hybrid PFSR 145×GP 83 (-1253.63) whereas, the highest value for SCA was shown by the hybrid GP 82×GP 83 (1333.17). Five hybrids (PFSR 204× GP 107, GP 327× GP 36, GP 329×GP 83, PFSR 145×GP 69 and GP 82×GP 83) exhibited the significant and positive SCA effect for grain yield. Similar results for grain yield was reported by Kanoosh [6], Karim *et al.* [26], Ambikabathy *et al.* [23], Kamara *et al.* [29], Abdulazeez *et al.* [19], Kumar *et al.* [11] and Suyadi *et al.* [10].

Table 3. General combining ability effects of 6 lines and 5 testers across three locations.

S. No.	Genotypes	Characters										
		Days to 50% tasseling	**Days to 50% silking**	**Days to maturity**	**Plant height (cm)**	**Ear height (cm)**	**Ear length (cm)**	**Ear girth (cm)**	**Number of Kernel per ear**	**Number of kernels per row**	**100 kernel weight (g)**	**Grain yield (kg ha^{-1})**
	Lines											
1	PFSR 393	-2.31**	-2.33**	-1.78**	-0.00	1.25	0.10	0.13	2.10	-0.25	-0.31	184.37
2	PFSR 204	0.28	0.30	0.34	0.24	2.09	-0.14	-0.52**	-20.97**	-0.02	-0.38	-171.84
3	GP 329	-0.52	-0.52	-0.50	3.10	0.23	0.50	0.43*	56.74**	1.43**	1.38**	372.16*
4	GP 327	1.25 **	1.23**	1.01*	0.55	1.86	0.00	-0.20	-11.06	0.28	-0.11	48.26
5	PFSR 145	-0.78 **	-0.80**	-2.48**	-3.44*	-3.44**	-0.16	-0.02	-32.11**	-0.70	-0.07	-98.37
6	GP 82	0.52 *	0.56*	3.41**	-0.45	-2.00	-0.30	0.18	5.310	-0.75*	-0.49	-334.59*
	GCA (Line)	0.25	0.25	0.47	2.12	1.05	0.27	0.18	5.65	0.37	0.40	106.62
	gi-gj (Line)	0.36	0.35	0.67	3.00	1.49	0.38	0.26	8.00	0.53	0.57	150.79
	Tester											
1	GP 36	-1.39 ***	-1.36 ***	-2.83**	3.10	1.24	-0.10	0.03	-16.51*	-0.39	-0.90*	-268.47 *
2	GP 69	0.97 ***	0.71 **	2.41**	-2.33	-1.54	-0.34	0.04	-13.54*	0.14	0.09	145.16
3	GP 83	0.97 ***	1.02 ***	1.00*	-4.63 *	0.50	-0.22	-0.10	21.88**	-0.62	0.12	-168.39
4	GP 86	0.97 ***	0.99 ***	0.49	0.57	-1.37	0.38	-0.03	-2.75	1.12**	0.40	65.70
5	GP 107	-1.52 ***	-1.36 ***	-1.08 *	3.28	1.16	0.28	0.06	10.94*	-0.24	0.27	225.99 *
	GCA (Tester)	0.2359	0.2322	0.43	1.93	0.96	0.25	0.17	5.16	0.34	0.37	97.3362
	gi-gj (Tester)	0.3337	0.3283	0.61	2.74	1.36	0.35	0.24	7.30	0.48	0.52	137.6542

**Significance at 5% probability, **significance at 1% probability*

Table 4. Specific combining ability effects of 30 crosses evaluated over three locations.

S. No.	Genotypes	Characters										
		Days to 50% tasseling	**Days to 50% silking**	**Days to maturity**	**Plant height (cm)**	**Ear height (cm)**	**Ear length (cm)**	**Ear girth (cm)**	**Number of Kernel per ear**	**Number of kernels per row**	**100 kernel weight (g)**	**Grain yield (kg ha^{-1})**
1	PFSR 393×GP 36	-3.57**	-3.66**	-7.10**	-4.82	-1.00	-0.70	-0.44	-11.34	-2.41**	-0.94	-287.15
2	PFSR 393×GP 69	-1.10	-1.08	4.48**	1.41	-1.41	-1.42*	0.14	9.51	1.71*	-1.31	-474.97*
3	PFSR 393×GP 83	3.39**	3.44**	4.39**	-3.62	-1.13	0.80	0.50	45.55**	2.52**	3.65**	275.33
4	PFSR 393×GP 86	4.39**	4.63**	6.24**	8.03	5.71*	1.00	-0.33	-3.78	0.76	1.07	127.17
5	PFSR 393×GP 107	-3.10**	-3.33**	-8.01**	-1.00	-2.16	0.31	0.13	-39.94**	-2.59**	-2.46**	359.621
6	PFSR 204× GP 36	-6.01**	-5.96**	-9.73**	2.92	2.48	-0.65	0.14	31.99*	1.96*	0.95	133.31
7	PFSR 204× GP 69	1.461*	1.78**	2.68*	-2.84	-1.12	0.17	0.06	-3.34	-0.80	-1.74	-216.19
8	PFSR 204× GP 83	1.12	1.14*	2.09	-3.40	-2.21	1.18	-0.64	-16.19	-1.69*	-0.61	-624.18*
9	PFSR 204× GP 86	1.79**	1.83**	1.94	-0.05	0.90	-0.27	0.48	-13.40	0.31	-1.65	163.74
10	PFSR 204× GP 107	1.62**	1.20*	3.01**	3.37	-0.04	-0.43	-0.05	0.93	0.21	3.06**	543.32*
11	GP 329×GP 36	-0.07	0.3	2.94**	-1.12	-0.38	-1.77**	-0.24	-78.52**	-2.06*	-2.28*	-1182.41**
12	GP 329×GP 69	0.56	0.71	-3.80**	0.30	3.34	0.14	0.34	6.94	0.93	0.61	22.63
13	GP 329×GP 83	-3.43*	-3.52*	-6.36**	2.57	-1.68	1.14	-0.13	-15.44	-0.16	1.07	686.76**
14	GP 329×GP 86	1.89**	1.43*	2.05	0.19	-1.73	-0.19	0.36	57.07**	1.18	0.90	373.83
15	GP 329×GP 107	-0.93	-1.03	-0.80	-1.94	0.45	0.67	-0.33	29.95*	0.11	-0.30	99.17
16	GP 327× GP 36	3.68**	3.43**	10.93**	2.21	0.11	0.92	0.19	22.88	1.08	1.08	597.72*
17	GP 327×GP 69	0.49	0.51	-3.65**	4.28	-0.85	0.47	-0.98*	2.11	-0.95	-0.34	-50.79
18	GP 327× GP 83	-2.67**	-2.28**	-5.40**	-2.28	-0.51	-1.41*	0.53	-41.74**	-0.15	-1.64	-417.39
19	GP 327× GP 86	-2.17**	-1.92**	-4.05**	-1.19	0.86	-0.49	0.29	17.11	-1.54	-0.55	-82.11
20	GP 327× GP 107	0.66	0.26	2.18*	-3.03	0.39	0.51	-0.03	-0.37	1.56	1.46	-47.41
21	PFSR 145×GP 36	2.22**	1.96**	2.74*	2.37	-0.64	1.40*	0.37	39.03**	0.46	0.17	414.13
22	PFSR 145×GP 69	0.52	0.88	1.84	3.27	4.08	-0.01	0.3	1.96	-0.20	2.30*	768.94**
23	PFSR 145×GP 83	2.36***	2.07**	2.43*	-4.18	-1.00	-1.47*	-0.64	-34.32**	-1.66	-2.92**	-1253.63**
24	PFSR 145×GP 86	-6.47**	-6.72**	-8.55**	-2.53	0.67	0.57	-0.18	-1.06	1.41	1.69	315.36
25	PFSR 145×GP 107	1.36*	1.80**	1.51	1.06	-3.10	-0.48	0.15	-5.62	-0.01	-1.24	-244.79
26	GP 82×GP 36	3.75**	3.93**	0.19	-1.57	-0.55	0.80	-0.02	-4.05	0.95	1.03	324.40
27	GP 82×GP 69	-1.93**	-2.81**	-1.552	-6.44	-4.02	0.64	0.12	-17.19	-0.68	0.49	-49.60
28	GP 82×GP 83	-2.77**	-2.95**	-3.13**	10.92*	6.55**	-0.24	0.38	62.15**	1.15	0.46	1333.11**
29	GP 82×GP 86	0.56	0.73	2.37*	-4.45	-6.43**	-0.62	-0.62	-55.95**	-2.13*	-1.47	-898.01**
30	GP 82×GP 107	0.39	1.1	2.11*	1.54	4.45	-0.58	0.14	15.05	0.70	-0.51	-709.90**
	SCA	0.57	0.56	1.05	4.74	2.36	0.61	0.42	12.64	0.84	0.916	238.42
	Sij - Skl	0.81	0.80	1.49	6.71	3.34	0.86	0.59	17.88	1.19	1.29	337.18

	Sij - Sik	0.96	0.95	1.77	7.94	3.96	1.02	0.70	21.16	1.40	1.53	398.95

*Significance at 5% probability, **significance at 1% probability

4. CONCLUSION

GCA effects of parental lines revealed that PFSR 145 found to be good general combiner for traits such days to 50% tasseling, days to 50% silking, days to maturity, plant height and ear height hence, this line can be used as one of the parent in the development of early maturing short stature draught tolerant hybrid. PFSR 393 and GP 36 were the good general combiners for earliness traits. On the other hand, GP 329 is best general combiner for most of the yield attributing traits hence, found to be most promising parental line for the development of potential hybrid. Similarly, PFSR 204× GP 36 was the good general combiner for earliness and some of the yield contributing trait while, hybrid GP 82×GP 83 found to be the best specific combiner for days to 50% tasseling, days to 50% silking, days to maturity, number of kernels per ear and grain yield. The hybrid GP 82×GP 83 can be tested extensively for the development of potential early maturing hybrids.

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