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COMBINING ABILITY STUDIES FOR GRAIN YIELD AND YIELD CONTRIBUTING CHARACTERS IN PIGEONPEA [*Cajanus cajan* (L.) Millsp.]

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ABSTRACT
The experiment was undertaken to study the combining ability for yield and its contributing traits in pigeonpea. The experimental material consisted of twelve parents and 27 F_1s produced from line × tester mating design in randomised block design for eleven characters. The mean squares due to gca, sca effects were significant for grain yield and yield contributing traits studied. The negative gca effect was desirable in days to 50 % flowering, days to maturity, which was observed in ICPA 2089, ICPA 2156 among lines and among testers it was observed in ICPL 88039. ICPL 161 and ICPL 149 had desirable gca effect for grain yield per plant. ICPA 2039 × ICPL 88039 recorded significant negative sca effect for days to 50% flowering and days to maturity. Ten crosses exhibited significant positive sca effects for grain yield. The parents with good gca could be further used in the future hybridization programmes.

KEYWORDS: Combining ability, gca effects, sca effects, line × tester analysis

INTRODUCTION
Pigeonpea [*Cajanus cajan* (L.) Millsp.] is one of the prominent legume crops of tropics and sub-tropics of Asia and Africa. It is a short-lived perennial shrub cultivated annually for grain purpose. Based on the genetic diversity of the crop, Van der Maesen (1980) concluded that India was the primary center of origin and Africa was the secondary center of origin of pigeonpea. It is drought-tolerant and possess the ability to use residual moisture at the time of dry season (Sheldrake 1984). The crop is primarily cultivated for de-hulled split peas, however immature green seeds and pods are also consumed fresh as a green vegetable. The green leaves serve as animal fodder. Pigeonpea plants add organic matter to the soil by fixing 40 kg ha^{-1} atmospheric nitrogen (Kumar Rao *et al.* 1983) through fallen leaves. The roots contribute to plant growth by releasing soil-bound phosphorus (Ae *et al.* 1990). In India, pigeonpea is grown in an area of 5.21 million hectares with a production of 4.23 million tonnes (D.E.S, 2017). Although India leads the world both in area and production of pigeonpea, its productivity is lower (673 kg/ha) than the world average (762.4 kg/ha) (FAOSTAT 2015).
To break the yield plateau, hybrid technology, which has been profitably used in a number of cereals, fruits, and vegetable crops was attempted in pigeonpea. In 1974, a source of genetic male-sterility (GMS) was identified. As a consequence, a GMS based pigeonpea hybrid ICPH 8 was released in 1991 in India (Saxena *et al.* 1992). Due to the limitation of large-scale hybrid seed production in GMS-based hybrids, the development of cytoplasmic male-sterility (CMS) became imperative. The success of CGMS systems relies on the availability of stable CMS lines and good fertility restorers. Combining ability studies helps in identifying the good parents which can be further used in the hybridization programme. Keeping this in view, the present study was conducted to identify the best parents for hybridization on the basis of their general and specific combining ability with respect to the grain yield and its contributing characters.

MATERIALS & METHODS
In the present experiment twelve parents *viz*., three lines and nine testers were crossed in L × T fashion. ICPA 2039, ICPA 2089, ICPA 2156 constituted the lines and nine testers were ICPL 88034, ICPL 88039, ICPL 149, ICPL 161, ICPL 81-3, ICPL 89, ICPL 90048, ICPL 86022, ICPL 92047. Hand pollination was carried out to obtain the crossed seeds during *kharif* 2015-16 at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru ($17^0 53^1$N, $78^0 27^1$E, 545.5MS), India. The resultant twenty seven hybrids along with their parents were evaluated in a randomized block design with three replications during *kharif* 2016-17. Each entry was sown in four rows of four metres length with a spacing of 75 x 30 cms from row to row and plant to plant respectively on 4^{th} of July, 2016.
Five competitive plants of each entry were selected randomly in each replication for recording the observations of eleven characters *viz.,* plant height (cm), days to 50% flowering, pollen fertility, days to maturity, number of primary branches per plant, number of secondary branches per plant, number of pods per plant, number of seeds per pod, 100 seed weight (g), grain yield per plant (g), harvest index (%). To record the pollen fertility observation 2% acetocaramine solution was used. Five well developed flower buds were collected at the time of anthesis from each plant. From each bud, the anthers were collected on a glass slide and crushed with a drop of 2% acetocaramine stain and examined under a light microscope. The mean value of pollen fertility/sterility of five plants was considered as pollen fertility (%) for that genotype. The general combining ability (GCA) and

specific combining ability (SCA) variances were worked out as per the method given by Kempthorne (1957).

RESULTS & DISCUSSION

The analysis of variance (ANOVA) for line × tester is represented in the table1. The mean sum of squares (MSS) of the treatments were partitioned into parent, cross and parent x cross. The results showed that all the parameters for parent, cross and parent x cross were found significant for plant height, days to 50% flowering, pollen fertility, days to maturity, number of secondary branches per plant, number of pods per plant, 100 seed weight, grain yield per plant and harvest index. The mean sum of squares in the analysis of variance due to lines were significant for all the characters except pollen fertility, number of primary branches per plant , number of seeds per pod , 100 seed weight and harvest index indicating the importance of general combining ability and additive gene effects. The mean sum of squares due to testers were significant for the characters plant height and 100 seed weight indicating the importance of general combining ability and additive gene effects. The mean sum of squares due to line x tester were significant for all the characters except number of primary branches per plant, number of secondary branches per plant and number of seeds per pod indicating the impact of specific combining ability and non additive gene effects.

The proportional contribution of lines, testers, and line x testers for various characters are presented in Table 2. The data revealed that contribution of line x tester was higher than both lines and testers for characters pollen fertility (61.33%), days to maturity (51.05%), number of secondary branches per plant (45.64%), number of seeds per pod (55.62%), grain yield per plant (41.23%) and harvest index (65.98%). The contribution of tester was highest for plant height (41.13%) and 100 seed weight (51.94%) than line and line x tester. The contribution of lines was more than testers and line x tester for the character days to 50% flowering (53.07%) and number of pods per plant (43.97%).

Combining Ability Analysis

Investigation of GCA effects (Table 3) revealed that the parents ICPA 2039 among lines, ICPL 161, ICPL 149, ICPL 90048 among testers were the good general combiners for grain yield and most of the yield contributing characters. Hence these good general combiners of males and females may be extensively used in future for pigeonpea breeding programmes. The negative GCA effect was desirable in days to 50 % flowering, days to maturity, which was observed in ICPA 2089, ICPA 2156 among lines and among testers it was observed in ICPL 88039. Among these parents, ICPL 161 and ICPL 149 had desirable GCA effect for grain yield per plant, plant height, number of secondary branches per plant, number of pods per plant, number of seeds per pod and harvest index. In general, good general combiners for grain yield also had good or average combining ability for one or more yield components. In most of the parents high GCA effects were associated with high *per se* mean for yield and yield components. It is important to mention here that the parents which showed good GCA effects for grain yield per plant also indicated significantly positive GCA effects for number of pods per plant. The results are in corroborance with the findings of Banu *et al.*, (2006), Kumar *et al.*, (2009), Vaghela *et al.*, (2009), Shoba and Balan (2010) and Sudhir *et al.*, (2017).

Specific combining ability effect is the index to determine usefulness of a particular combination in the exploitation of heterosis. The estimate of SCA effects of the hybrids are presented in Table 4. For the trait plant height, the cross ICPA 2089 X ICPL 149 and ICPA 2039 X ICPL 149 exhibited significant negative SCA effects. For days to 50% flowering and days to maturity negative SCA effects are desirable. Only one cross ICPA 2039 X ICPL 88039 recorded significant negative SCA effect over both the traits. None of the crosses recorded significant positive SCA effect for number of primary branches per plant. For the trait number of secondary branches per plant, only one cross showed significant positive SCA effect *viz.*,ICPA 2156 X ICPL 88039. Eight crosses exhibited significant positive SCA effect for pollen fertility. Maximum significant positive SCA effect was shown by ICPA 2156 X ICPL 89 followed by ICPA 2156 X ICPL 161. These results are in agreement with Wanjari *et al.*,(2007). For the trait number of pods per plant ten crosses exhibited significant positive SCA effects. Maximum significant positive SCA effect was registered by ICPA 2039 X ICPL 161 followed by ICPA 2156 X ICPL 86022. Only one cross recorded significant positive SCA effect *viz.*,ICPA 2156 X ICPL 90048 for the trait number of seeds per pod. For the trait 100 seed weight, three crosses exhibited significant positive SCA effects. Maximum significant positive SCA effect was registered by the cross ICPA 2089 X ICPL 92047.

Ten crosses exhibited significant positive SCA effect for grain yield. Most promising crosses in the order of their merit are ICPA 2039 X ICPL 161 (35.63), ICPA 2156 X ICPL 86022 (22.53), ICPA 2039 X ICPL 90048 (24.02), ICPA 2089 X ICPL 81-3 (15.01), ICPA 2089 X ICPL 89 (11.56), ICPA 2039 X ICPL 149 (8.85), ICPA 2156 X ICPL 88039 (8.37), ICPA 2156 X ICPL 89 (8.37) and ICPA 2156 X ICPL 92047 (7.86) for grain yield per plant. For the trait harvest index four crosses recorded significant positive SCA effects. Maximum significant positive SCA effect was exhibited by ICPA 2089 X ICPL 89 followed by ICPA 2156 X ICPL 90048. These results are in agreement with the findings of Shoba and Balan (2010) and Gupta *et al.*, (2011).

This study clearly indicated that there was no particular relationship between positive and significant SCA effects of crosses with GCA effects of their parents for characters under study. This was in agreement with the findings of Pandey *et al.*, (2014) and Sudhir *et al.*, (2017).

TABLE1: ANOVA for line × tester analysis

Sources of variation	d. f.	Mean sum of squares										
		Plant height (cm)	Days to 50 % flowering	Pollen fertility (%)	Days to maturity	No. of primary branches/plant	No. of secondary branches /plant	Number of pods per plant	No. of seeds per pod	100 seed weight (g)	Grain yield per plant (g)	Harvest Index
Treatment	38	638.77**	79.87**	2046.23**	126.53**	1.58*	6.84**	17430.13**	0.08**	0.94**	1430.75**	113.93**
Replications	2	123.96	14.80	1.70	40.26	2.05	2.78	384.34	0.04	0.06	11.36	0.89
Parent (P)	11	459.42**	132.94**	6007.32**	217.90**	3.30**	4.24*	18128.51**	0.11**	1.27**	1307.45**	113.83**
Crosses (C)	26	525.90**	57.12**	65.41**	60.61**	0.79	7.25**	17538.31**	0.07	0.81**	1518.42**	117.19**
P x C	1	5546.48**	87.48**	9975.72**	835.56**	3.22**	25.03**	6935.13**	0.01	0.61	507.67**	30.23
Line	2	2552.01**	394.16**	168.10	202.31*	1.27	25.76**	100271.93**	0.02	0.88	7695.10**	189.37**
Tester	8	703.07*	45.15	40.18	45.85	1.07	7.91	13939.54	0.09	1.36*	975.95	82.22
LinexTester	16	184.05**	20.98**	65.19**	50.28**	0.58	4.61	8996.00**	0.06	0.52*	1017.57**	125.65**
Error	76	45.19	5.51	6.04	19.56	0.85	2.18	137.55	0.04	0.20	30.72	14.85

* - Significant at 5 % level of significance ** - Significant at 1 % level of significance

Note: A lines and B lines are isogenic except for pollen fertility. The observations of yield and yield contributing characters except pollen fertility were recorded on B-lines (ICPB 2039, ICPB 2089 and ICPB 2156).

TABLE 2: Proportional contribution of lines, testers and line x tester

Sr. No.	Characters	Line (%)	Tester (%)	Line x tester (%)
1.	Plant height (cm)	37.32	41.13	21.53
2.	Days to 50% flowering	53.07	24.32	22.06
3.	Pollen fertility (%)	21.14	14.40	64.44
4.	Days to maturity	25.67	23.27	51.05
5.	Number of primary branches per plant	12.38	41.96	45.64
6.	Number of secondary branches per plant	27.33	33.55	39.11
7.	Number of pods/ plant	43.97	24.45	31.56
8	Number of seeds / pod	2.21	42.16	55.62
9.	100 seed weight (g)	8.42	51.94	39.63
10.	Grain yield per plant (g)	38.98	19.77	41.23
11.	Harvest Index	12.42	21.58	65.98

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TABLE 3. General combining ability of parents in pigeonpea

Sr. No	Parents	Plant height (cm)	Days to 50 % flowering	Pollen fertility	Days to maturity	No. of primary branches per plant	No. of secondary branches per plant	No. of pods per plant	No. of seeds per pod	100 seed wt. (g)	Grain yield per plant (g)	Harvest Index (%)
	Female parents											
1.	ICPA 2039	11.02**	4.40**	1.79**	2.95**	0.23	0.83**	69.84**	-0.03	-0.11	19.37**	-2.90**
2.	ICPA 2089	-7.35**	-2.53**	-2.85**	-2.46**	-0.20	0.25	-27.44**	0.02	-0.10	-7.78**	0.61
3.	ICPA 2156	-3.68**	-1.86**	1.06**	-0.49	-0.04	-1.08**	-42.40**	0.01	0.21*	-11.59**	2.29**
	Male parents											
4.	ICPL 88034	0.52	-0.68	0.86	-3.01*	-0.20	1.15*	13.31**	-0.10	-0.01	2.13	-5.70**
5.	ICPL 88039	-10.75**	-2.46**	-1.22	-2.79*	-0.34	0.03	-35.36**	0.19*	0.14	-4.20*	2.85*
6.	ICPL 149	15.63**	2.99**	2.48**	2.21	-0.24	-1.05	50.95**	0.03	-0.31	9.68**	2.37*
7.	ICPL 161	4.97*	2.77**	-1.46*	2.65	0.09	1.11*	57.45**	-0.03	-0.53**	13.91**	2.68*
8.	ICPL 81-3	8.63**	2.43**	-0.48	1.32	0.48	0.53	-0.38	-0.02	0.26	2.34	0.38
9.	ICPL 89	-9.03**	-0.90	-3.34**	-0.57	0.34	0.49	-50.69**	-0.01	0.16	-14.20**	-3.66**
10.	ICPL 90048	-5.75*	-0.35	0.67	2.32	0.45	-0.08	-0.01	0.13*	0.77**	8.85**	-1.56
11.	ICPL 86022	-6.70**	3.12**	3.50**	-2.12	-0.29	-1.58**	-48.26**	-0.09	-0.17	-16.37**	1.60
12.	ICPL 92047	2.48	-0.68	-1.00	-0.01	-0.31	-0.59	12.98**	-0.09	-0.32*	-2.13	1.03
	SE ±Gi (line)	1.29	0.49	0.009	0.82	0.17	0.31	2.30	0.04	0.09	1.04	0.68
	SE ±Gj (tester)	2.23	0.85	0.016	1.42	0.30	0.54	3.98	0.07	0.16	1.81	1.18

* - Significant at 5 % level of significance ** - Significant at 1 % level of significance

Note: A lines and B lines are isogenic except for pollen fertility. The observations of yield and yield contributing characters except pollen fertility were recorded on B-lines (ICPB 2039, ICPB 2089 and ICPB 2156).

TABLE 4: Specific combining ability of crosses in pigeonpea

Sr. No	Crosses	Plant height (cm)	Days to 50 % flowering	Pollen fertility (%)	Days to maturity	No. of primary branches per plant	No. of secondary branches per plant	No. of pods per plant	No. of seeds per pod	100 seed wt. (g)	Grain yield Per Plant (g)	Harvest Index (%)
1.	ICPA2039 X ICPL88034	-6.69	-2.28	0.06	-4.51	-0.18	-1.97*	12.25	0.14	-0.01	3.74	1.10
2.	ICPA2039 X ICPL88039	-2.76	-4.84**	4.09**	-7.06**	-0.07	1.25	50.15**	-0.15	-0.25	-15.92**	-0.55
3.	ICPA2039 X ICPL149	8.20*	1.05	-0.26	4.27	-0.07	-0.11	11.87	-0.06	0.53*	8.85**	1.07
4.	ICPA2039 X ICPL161	7.86*	0.27	-0.68	0.83	-0.20	-0.56	107.55**	0.04	0.58*	35.63**	0.09
5.	ICPA2039 X ICPL81-3	2.53	1.94	3.14*	3.49	1.04*	-0.58	-37.13**	-0.04	0.06	-12.47**	-1.60
6.	ICPA2039 X ICPL89	0.86	0.94	-7.06**	1.72	-0.49	0.15	-49.18**	-0.01	-0.51	-19.92**	-2.60
7.	ICPA2039 X ICPL90048	-6.56	3.38*	-0.81	2.83	0.37	1.51	67.37**	-0.16	0.15	24.02**	1.40
8.	ICPA2039 X ICPL86022	-9.47*	-1.17	-2.45*	0.27	-0.30	0.83	-55.05**	0.13	-0.11	-19.59**	7.22**
9.	ICPA2039 X ICPL92047	6.02	0.72	3.96**	-1.84	-0.10	-0.53	-7.55	0.10	-0.43	-4.34	-6.13**
10.	ICPA2089 X ICPL88034	-0.99	-0.02	3.04*	1.23	0.07	-0.59	17.66*	-0.21	0.17	4.89	2.33
11.	ICPA2089 X ICPL88039	2.15	-0.91	4.23**	0.35	0.09	-0.41	25.80**	0.14	-0.17	7.56*	2.47
12.	ICPA2089 X ICPL149	7.90*	-0.69	-0.08	-4.65	0.24	0.94	2.48	0.16	-0.43	-3.33	-3.74
13.	ICPA2089 X ICPL161	-5.43	0.53	-4.04**	2.23	-0.10	0.35	-43.23**	-0.01	-0.34	-13.55**	-0.72
14.	ICPA2089 X ICPL81-3	-2.10	-1.80	-4.62**	-1.10	-0.49	0.45	52.35**	0.02	-0.26	15.01**	-0.51
15.	ICPA2089 X ICPL89	-1.10	1.20	0.01	-0.54	0.34	-0.01	25.10**	-0.03	0.04	11.56**	12.08**
16.	ICPA2089 X ICPL90048	6.28	-0.69	2.09	1.57	-0.62	0.38	52.08**	-0.11	0.06	-15.67**	-11.26**
17.	ICPA2089 X ICPL86022	2.90	2.09	3.13*	-2.65	0.29	-0.66	-20.20**	-0.02	0.24	-2.94	-2.23
18.	ICPA2089 X ICPL92047	-9.61*	0.31	-3.76**	3.57	0.16	-0.45	-7.87	0.05	0.68*	-3.52	1.57
19.	ICPA2156 X ICPL88034	7.68*	2.31	-3.10*	3.27	0.11	2.57**	-29.91**	0.06	-0.16	-8.63**	-3.44
20.	ICPA2156 X ICPL88039	0.61	5.75**	-8.32**	6.72**	-0.02	-0.84	24.35**	0.01	0.42	8.37**	-1.92
21.	ICPA2156 X ICPL149	-16.10**	-0.36	0.34	0.38	-0.18	-0.83	-14.36*	-0.10	-0.10	-5.52	2.67
22.	ICPA2156 X ICPL161	-2.43	-0.80	4.72**	-3.06	0.30	0.21	-64.32**	-0.04	-0.24	-22.08**	0.63
23.	ICPA2156 X ICPL81-3	-0.43	-0.14	1.47	-2.40	-0.55	0.13	-15.23*	0.02	0.20	-2.54	2.10
24.	ICPA2156 X ICPL89	0.23	-2.14	7.05**	-1.17	0.15	-0.14	24.09*	0.04	0.47	8.37**	-9.48**
25.	ICPA2156 X ICPL90048	0.28	-2.69	-1.28	-4.40	0.24	-1.90*	-15.29*	0.26*	-0.21	-8.35**	9.86**
26.	ICPA2156 X ICPL86022	6.57	-0.91	-0.68	2.38	0.01	-0.17	75.25**	-0.11	-0.13	22.53**	-4.99**
27.	ICPA2156 X ICPL92047	3.59	-1.02	-0.20	-1.73	-0.06	0.98	15.42*	-0.15	-0.25	7.86*	4.56*
	SEij	3.87	1.47	0.12	2.46	0.53	0.95	6.90	0.13	0.27	3.14	2.05
	C.D. 5%	7.78	2.72	2.37	5.12	1.07	1.71	13.59	0.23	0.52	6.42	4.46

* - Significant at 5 % level of significance ** - Significant at 1 % level of significance

CONCLUSION

Combining ability analysis provides information about the usefulness of individuals if employed as the parents in the hybridization programme as well as simultaneously to screen the hybrids. In addition to this, it also ascertains the magnitude and nature of quantitative genetic variation which could be of great use to plant breeders for deciding efficient and effective breeding programme.. On the basis of *per* se performance and combining ability, the parents ICPA 2039, ICPL 88039, ICPL 161 and ICPL 149 can be used for future hybridization programmes. Promising crosses exhibiting significant positive SCA effect *viz.*,ICPA 2039 X ICPL 161, ICPA 2156 X ICPL 86022 and ICPA 2039 X ICPL 90048 for grain yield/plant may be considered for the hybrid breeding programme.

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