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Gene Action and Combining Ability Estimates Using Cytoplasmic Male Sterile Lines to Develop Pigeonpea [*Cajanus cajan* (L.) MILLSP.] hybrids

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ABSTRACT

Evaluation of 25 F_1 hybrids were involving five CMS lines and five testers in line × tester fashion, data recorded on twelve agronomical characters. The estimation of gca effects for parents indicated that among females, ICP-2098A was good general combiner for yield and yield attributing traits, whereas in males ICPL-87119 was good general combiner for yield and yield attributing characters. In the crosses *viz.,* ICP-2210A x ICPL-87119 and ICP-2098A x ICPL-87119 were the best specific combinations for seed yield per plant and its attributing character.

Keywords *Combining ability, Pigeon pea, Cytoplasmic male sterility.*

Pigeonpea [*Cajanus cajan* (L.) Millsp.] is a short-lived perennial member of family *Fabaceae* and it is invariably cultivated as annual crop. Pigeonpea is an often cross pollinated (20-70%) crop with 2n = 2x = 22 diploid chromosome number (Saxena *et al.,* 1990). Pigeonpea is a hardy, widely adapted and drought tolerant crop. Pigeonpea is grown worldwide on 5.2 m ha land in about 50 countries and 77 % of its area is in India (Anonymous, 2013). At present, pigeonpea is cultivated on 4.4 million ha area with 2.89 million tones production with a productivity 655 kg/ha during year 2010-11 (Anonymous, 2013). Gujarat grows pigeonpea on around 2.77 Lakh hectares with an annual production and productivity of 2.73 Lakh tones and 986 kg/ha, respectively (Anonymous, 2013). Pigeonpea is a rich source of proteins, carbohydrates and certain vital minerals useful for health (Gopalan *et al* 1971). Protein content of commonly grown pigeonpea cultivars ranges between 17.9 g and 24.3 g per 100 g for whole grain samples and between 21.1 g and 28.1 g per 100 g for split grains (Salunkhe *et al*. 1986). Combining ability analysis is a powerful tool to discriminate good as well as poor combiner and selecting out appropriate parental material and at the same time provide information about nature of gene action involved in the inheritance of various traits.

MATERIALS AND METHODS

The crossing programme was carried out using 5 females and 5 males pollination at pulse research station, Navsari during *late kharif* - 2014, 25 crosses were obtained in line x tester mating design. The experiment was laid out in a Randomized Block Design with three replications during *Kharif-2015*. Each entry was planted in a single row consisting of 10 plants in each row with a spacing 90 x 20 cm. Five competitive plants were randomly selected and tagged excluding border plants to minimize border effects. Observations on tagged plants except days to 50 per cent flowering and days to maturity (plot basis) were recorded on the following twelve characters and mean values over five plants were subjected to statistical analysis.The variation among the hybrids was partitioned further into sources attributed to general combining ability and specific combining ability components in accordance with the procedure suggested by Kempthorne (1957).

RESULTS AND DISCUSSION

The genetic variances were estimated from the analysis of variance for combining ability for twelve different characters studied in the present investigation and its results are presented in Table-1. The analysis of variance for combining ability revealed that mean sum of squares due to females were found significant for days to maturity, 100-seed weight and harvest index. Whereas for males, significant mean sum of squares were noticed for days to 50% flowering, days to maturity, plant height, pods per plant, pod length, 100-seed weight, harvest index and protein content. Highly significant mean sum of squares due to females x males were observed for all the characters except seed yield per plant. General combining ability (gca) variances for females ($ó^2f$) were observed significant for days to maturity, 100-seed weight and harvest index. Similarly, general combining ability (gca) variances for males ($ó^2m$) were found significant for all characters except primary branches per plant, seeds per pod and pollen fertility. General combining ability (gca) variances for females ($ó^2f$) were observed significant for days to maturity, 100-seed weight and harvest index. Similarly, general combining ability (gca) variances for males ($ó^2m$) were found significant for all characters except primary branches per plant, seeds per pod and pollen fertility. Variances estimates due to general combining ability ($ó^2gca$) were observed to be significant for all characters except pollen fertility. Similarly, the estimates of variance due to specific combining ability ($ó^2sca$) were observed highly significant for all characters. The ratio of s^2gca / s^2sca revealed that the characters like days to 50 per cent flowering, primary branches per plant, pods per plant, pod length, seeds per pod, seed yield per plant, protein content and pollen fertility manifested less

Table 1. Mean squares due to General and Specific combining ability for different characters in pigeonpea

Source of Variations	DF	Days to 50% flowering	Days to maturity	Plant height	Primary branches per plant	pods per plant	Pod length	Seeds per pod	100-seed weight	Seed yield per plant	Harvest index	Protein content	Pollen fertility
Replication	2	10.17	42.04	12.41	0.43	298.69	0.21	0.12	0.21	98.91	8.10	2.61	2.07
Hybrids	24	169.16**	828.69**	2436.57**	12.26**	3936.19**	2.45**	0.98 **	9.06**	2494.03	398.64**	14.85**	60.07**
Females	4	76.61	768.43*	1121.60	13.18	4236.48	0.78	0.62	11.69*	3390.06	503.13**	15.56	48.08
Males	4	498.25*	3301.67**	10335.88**	19.56	10259.49*	8.50**	2.22	27.32**	5869.52	1605.97**	31.90*	86.33
Female x Male	16	110.03**	225.52**	790.49**	10.21**	2280.29**	1.36**	0.76 **	3.84**	1426.14	70.69*	10.40**	56.50**
Error	48	18.30	64.40	125.95	0.63	489.70	0.15	0.05	0.92	139.36	30.96	0.86	5.56
σ^2 F		3.95	47.15 *	65.0155	0.82	256.03	0.04	0.04	0.72 *	215.47	31.09 **	0.94	2.93
σ^2 M		32.06 *	216.03 **	679.30 **	1.25	657.56 *	0.55 **	0.15	1.76 **	380.76 *	104.62 **	2.02 *	5.48
σ^2 gca		18.00 **	131.59 **	372.15 **	1.04 *	456.79 **	0.29 **	0.09 *	1.24 **	298.11 **	67.86 **	1.48 **	4.20
σ^2 sca		30.91 **	54.78 **	214.70 **	3.14 **	628.07 **	0.40 **	0.23 **	1.00 **	422.68 **	11.34 *	2.98 **	17.43 **
σ^2 gca/σ^2 sca		0.58	2.40	1.73	0.33	0.72	0.73	0.04	1.24	0.71	5.98	0.50	0.24

* Significant at 5 % level, ** Significant at 1 % level

Table 2. Estimation general combining ability (GCA) effects of parents for various characters in pigeonpea

Parents	Days to 50% flowering	Days to maturity	Plant height	Primary branches per plant	pods per plant	Pod length	Seeds per pod	100-seed weight	Seed yield per plant	Harvest index (%)	Protein content (%)	Pollen fertility (%)
Lines												
ICP-2210A	-2.05	-6.60 **	5.32	0.48 *	19.68 **	0.15	0.02	0.13	8.28 *	3.19 *	0.64 *	1.30 *
ICP-2199A	-0.72	-1.73	-3.64	-1.56 **	1.43	-0.17	0.18 **	-0.28	-18.72 **	-2.84	-1.13 **	-0.05
ICP-2198A	0.48	4.80 *	-2.15	-0.12	-20.07 **	0.09	0.02	0.11	-2.37	-4.80 **	-0.51	-2.80 **
ICP-2188A	3.68 **	9.80**	-11.00 **	0.36	-13.49 *	-0.30 **	-0.34 **	-1.21 **	-7.67 *	-4.21 **	-0.41	-0.22
ICP-2098A	-1.39	-6.26 **	11.47 **	0.84 **	12.44 *	0.22 *	0.11 *	1.23 **	20.49 **	8.66 **	1.41 **	1.77 **
SE(gj)	1.07	2.02	3.12	0.23	5.14	0.10	0.05	0.23	3.25	1.56	0.31	0.53
SE (gi-gj)	1.52	2.86	4.42	0.32	7.27	0.14	0.08	0.33	4.59	2.21	0.44	0.75
Testers												
ICPL-87119	-6.12 **	-13.86 **	23.59 **	0.60 *	32.90 **	0.89 **	0.41 **	1.47 **	19.19 **	9.65 **	1.75 **	2.00 **
ICPR-4544	3.94 **	14.73 **	-31.43 ***	-1.48 **	-19.08 **	-0.99 **	-0.30 **	-1.14 **	-23.47 **	-8.14 **	0.42	-0.41
ICPR4543	-2.98 **	-7.00 **	10.15 **	1.08 **	6.48	-0.13	-0.26 **	0.32	6.15	3.17 *	-2.14 **	-2.88 **
ICPR-4502	7.94 **	17.26 **	-24.67 **	-0.96 **	-32.96 **	-0.34 **	-0.28 **	-1.64 **	-18.34 **	-13.46 **	0.55	-1.55 **
ICPR-4531	-2.78 *	-11.13 **	22.35 **	0.76 **	12.66 *	0.57 **	0.43 **	0.99 **	16.46 **	8.78 **	-0.59	2.84 **
SE(gj)	1.07	2.02	3.12	0.23	5.14	0.10	0.05	0.23	3.25	1.56	0.31	0.53
SE (gi-gj)	1.52	2.86	4.42	0.32	7.27	0.14	0.08	0.33	4.59	2.21	0.44	0.75

Table 3. Estimation of specific combining ability (sca) effects of hybrids for various characters in pigeonpea

Sr. No.	Hybrid	Days to 50% flowering	Days to maturity	Plant height	Primary branches per plant	pods per plant	Pod length	Seeds per pod	100-seed weight	Seed yield per plant	Harvest index (%)	Protein content (%)	Pollen fertility (%)
1	ICP-2210A x ICPL-87119	-2.28	-2.47	11.65	1.52 **	-5.24	-0.03	0.46 **	0.61	14.59 *	2.08	0.97	2.87 *
2	ICP-2210A x ICPR-4544	-0.28	0.67	-1.05	1.36 **	-12.85	0.08	-0.55 **	0.04	-8.64	0.40	0.17	0.81
3	ICP-2210A x ICPR-4543	4.52	-2.53	-21.27 **	-3.88 **	8.73	-0.13	-0.18	-0.13	-13.99	3.02	0.23	-5.43 **
4	ICP-2210A x ICPR-4502	-2.35	3.13	8.98	-0.16	12.22	0.21	0.12	0.16	10.19	-0.44	-0.72	-0.22
5	ICP-2210A x ICPR-4531	0.39	1.20	1.70	1.16 *	-2.86	-0.14	0.15	-0.68	-2.15	-5.07	-0.65	1.97
6	ICP-2199A x ICPL-87119	9.32 **	5.27	-14.46 *	-0.6	-35.64 **	-0.55 *	-0.29 *	-1.77 **	-30.86 **	-7.96 *	-0.13	-2.80 *
7	ICP-2199A x ICPR-4544	-7.34 **	5.40	3.71	-0.56	32.07 **	0.57 *	-0.23	-1.19 *	8.20	2.22	0.65	0.87
8	ICP-2199A x ICPR-4543	-8.54 **	-7.47	2.35	3.40 **	-23.22 *	-0.09	0.78 **	1.84 **	23.83 **	-2.07	0.36	0.81
9	ICP-2199A x ICPR-4502	4.92 *	-9.13 *	9.87	-0.48	38.93 **	0.70 **	0.10	1.19 *	-0.00	-2.61	1.40	4.38 **
10	ICP-2199A x ICPR-4531	1.65	5.93	-1.48	-1.76 **	-12.14	-0.62 **	-0.35 **	-0.06	-1.15	10.42 **	-2.28 **	-3.26 **
11	ICP-2198A x ICPL-87119	-1.41	-1.67	3.42	0.04	0.45	0.90 **	-0.30 *	0.74	17.16 *	5.57*	-2.55 **	-4.67 **
12	ICP-2198A x ICPR-4544	3.92	-7.87	12.33	0.88	-4.44	-0.88 **	0.32 **	1.14 *	-30.29 **	-3.49	-0.11	-0.99
13	ICP-2198A x ICPR-4543	1.72	18.60 **	-11.17	-0.36	-13.06	-0.35	-0.30 *	-0.75	9.95	-4.27	-1.05	1.78
14	ICP-2198A x ICPR-4502	-1.15	-2.73	-16.38 *	-1.04 *	-3.57	-0.55 *	-0.51 **	-1.46 **	-6.85	2.02	1.05	-2.63 *
15	ICP-2198A x ICPR-4531	-3.08	-6.33	11.81	0.48	20.62	0.89 **	0.79 **	0.34	10.03	1.17	2.67 **	6.51 ***
16	ICP-2188A x ICPL-87119	-2.68	0.73	-11.76	-1.92 **	25.56 *	-0.60 **	-0.26 *	-0.78	-15.98 *	-0.78	-1.15	2.66 *
17	ICP-2188A x ICPR-4544	5.65 *	4.87	-18.98 **	0.12	-21.98	-0.28	0.58 **	-0.69	11.01	-2.34	0.93	-2.19
18	ICP-2188A x ICPR-4543	2.79	-3.00	39.45 **	0.68	0.66	0.45 *	-0.09	-0.04	-25.52 **	0.21	1.41 *	0.12
19	ICP-2188A x ICPR-4502	-10.41 **	-8.00	4.31	2.20 **	13.95	0.71 **	0.47 **	0.69	31.88 **	4.79	0.65	5.53 **
20	ICP-2188A x ICPR-4531	4.65	5.40	-13.04	-1.08 *	-18.20	-0.28	-0.69 **	0.82	-1.38	-1.89	-1.85 *	-6.12 **
21	ICP-2098A x ICPL-87119	-2.95	-1.867	11.15	0.96	14.87	0.28	0.39 **	1.21 *	15.09 *	2.09	2.85 **	1.93
22	ICP-2098A x ICPR-4544	-1.95	-3.067	3.99	-1.80 **	7.19	0.51 *	-0.11	0.70	19.72 **	3.21	-1.64 *	1.50
23	ICP-2098A x ICPR-4543	-0.48	-5.6	-9.37	0.16	26.89 *	0.11	-0.19	-0.92	5.74	3.10	-0.95	2.71 *
24	ICP-2098A x ICPR-4502	8.98 **	16.73 **	-6.78	-0.52	-61.54 **	-1.07 **	-0.18	-0.57	-35.21 **	-3.76	-2.37 **	-7.06 **
25	ICP-2098A x ICPR-4531	-3.61	-6.2	1.01	1.20 *	12.58	0.15	0.10	-0.41	-5.34	-4.64	2.10 **	0.90
26	**S.E(S_{ij})±**	2.40	4.52	6.98	0.50	11.49	0.22	0.12	0.52	7.26	3.49	0.70	1.18
27	**S.E(S_{ij}- S_{kl}) ±**	3.40	6.39	9.88	0.71	16.25	0.30	0.17	0.74	10.27	4.94	0.99	1.67
28	**S.E(S_{ij}- S_{ik}) ±**	3.72	7.00	10.82	0.78	17.80	0.33	0.19	0.81	11.25	5.41	1.08	1.83

* Significant at 5 % level, ** Significant at 1 % level

Table 4. Summarized account of gca effects of parents for different characters in pigeonpea

Parents	Days to 50% flowering	Days to maturity	Plant height	Primary branches per plant	pods per plant	Pod length	Seeds per pod	100-seed weight	Seed yield per plant	Harvest index (%)	Protein content (%)	Pollen fertility (%)
Lines												
ICP-2210A	A	G	A	G	G	A	A	A	G	G	G	G
ICP-2199A	A	A	A	P	A	A	G	A	P	A	P	A
ICP-2198A	A	P	A	A	P	A	A	A	A	P	A	P
ICP-2188A	P	P	P	A	P	P	P	P	P	P	A	A
ICP-2098A	A	G	G	G	G	G	G	G	G	G	G	G
Testers												
ICPL-87119	G	G	G	G	G	G	G	G	G	G	G	G
ICPR-4544	P	P	P	P	P	P	P	P	P	P	A	A
ICPR4543	G	G	G	G	A	A	P	A	A	G	P	P
ICPR-4502	P	P	P	P	P	P	P	P	P	P	A	P
ICPR-4531	G	G	G	G	G	G	G	G	G	G	A	G

than unity, which indicated that preponderance of non-additive genetic variance for inheritance of these characters. The findings are in confirmation with Khorgade *et al.* (2000), Sekhar *et al.* (2004), Baskaran and Muthiah (2007), Kumar *et al.* (2009), Shobha and Balan (2010), Gupta *et al.* (2011), Bharate *et al.* (2011), Thiruvengadam and Muthiah (2012), Patel *et al.* (2013), Arbad *et al.* (2013), Yamanura *et al.* (2014), Pandey *et al.* (2014), Patil *et al.* (2014), Saroj *et al.* (2014) in pigeonpea. Days to maturity, plant height, 100-seed weight, harvest index manifested more than unity which indicated that preponderance of additive genetic variance for inheritance of this characters.

Estimation of General and Specific Combining Ability Effects

The estimates of general combining ability (gca) effect of ten parents including five females and five males and specific combing ability of twenty five hybrids are presented in Table-2 and Table-3, respectively.

General Combining Ability Effects

The parents were classified as good, average and poor combiners based on estimates of general combining ability effects (Table-4).The gca effects of ICPL-87119 parents revealed to be good general combiner for all the characters. The gca effects of ICPR-4531 parents revealed to be good general combiner for all the characters except average combiner for protein content. An overall appraisal of gca effects of parents revealed that ICP-2210A, ICP-2098A, ICPL-87119 and ICPR-4531 were found good general combiner for seed yield per plant. Thus, ICP-2210A, ICP-2098A, ICPL-87119 and ICPR-4531 may be useful in future breeding programme as parent to combine the yields and its contributing traits in the hybrid. Similarly, parents ICPL-87119, ICPR-4543 and ICPR-4531 showed significant gca effects in negative direction for days to 50 per cent flowering, hence these parents can be used in future breeding programme for development early pigeonpea materials.

Specific Combining Ability Effects

Comparative study of most promising hybrids having high sca effects for seed yield per plant along with gca effects of parents involved in the crosses showed in table-5 indicated that the sca effects of hybrids involved G x G, A x G and G x A gca effects of parents. Based on estimation of sca effects the crosses *viz.,* ICP-2210A x ICPL-87119 and ICP-2098A x ICPL-87119 registered high and significant sca effects for seed yield per plant and also possessed high sca effects for at least one yield contributing component.Such combination may be useful for isolating superior Hybrids.

The cross combination ICP-2210A x ICPR-4531, ICP-2098A x ICPR-4543, ICP-2098A x ICPR-4531 and ICP-2210A x ICPR-4543 showing low *sca* effect and poor combiner indicating that heterosis of these hybrid is might be exhibited due to major role of additive variances. This combination may be useful for isolating the desired transgressive segregant by checking the restoring ability of cross combination in every generation of transgressive segregants.

With specific combining ability and general

Table 5. A summary table showing the best *per se* performance along

Characters	Best specific combination	*Per se* performance	SCA	gca effects of the parents involved
	ICP-2210A x ICPL-87119	76.33	-2.28	A X G
Days to flowering	ICP-2210A x ICPR-4531	79.00	4.52	A X G
	ICP-2098A x ICPR-4531	79.00	-3.61	A X G
	ICP-2098A x ICPR-4531	134.00	-6.2	G X G
Days to maturity	ICP-2210A x ICPL-87119	134.67	-2.47	G X G
	ICP-2210A x ICPR-4531	138.00	1.20	G X G
	ICP-2210A x ICPL-87119	220.07	11.65	A X G
Plant height (cm)	ICP-2210A x ICPR-4531	218.33	1.70	A X G
	ICP-2098A x ICPL-87119	216.27	11.15	G X G
	ICP-2098A x ICPR-4531	11.80	1.20 *	G X G
Branches per plant	ICP-2210A x ICPL-87119	11.60	1.52 **	G X G
	ICP-2098A x ICPL-87119	11.60	0.96	G X G
	ICP-2210A x ICPL-87119	322.40	-5.24	G X G
Pods per plant	ICP-2210A x ICPR-4531	322.27	-2.86	G X G
	ICP-2098A x ICPL-87119	317.53	14.87	G X G
	ICP-2210A x ICPL-87119	7.62	-0.03	A X G
Pod length (cm)	ICP-2210A x ICPR-4531	7.61	-0.14	A X G
	ICP-2098A x ICPL-87119	7.58	0.28	G X G
	ICP-2210A x ICPL-87119	5.07	0.46 **	A X G
Seeds per pod	ICP-2210A x ICPR-4531	5.03	0.15	A X G
	ICP-2098A x ICPL-87119	4.84	0.39 **	G X G
	ICP-2210A x ICPR-4531	12.97	-0.68	A X G
100-seed weight (g)	ICP-2210A x ICPL-87119	12.84	0.61	A X G
	ICP-2098A x ICPL-87119	12.65	1.21 *	G X G
	ICP-2210A x ICPL-87119	162.83	14.59 *	G X G
Seed yield per plant (g)	ICP-2210A x ICPR-4531	160.61	-2.15	G X G
	ICP-2098A x ICPL-87119	158.30	15.09 *	G X G
	ICP-2210A x ICPL-87119	47.22	2.08	G X G
Harvest index (%)	ICP-2210A x ICPR-4531	46.36	-5.07	G X G
	ICP-2098A x ICPL-87119	45.54	2.09	G X G
	ICP-2210A x ICPL-87119	21.64	0.97	G X G
Protein content (%)	ICP-2098A x ICPR-4531	21.20	2.10 **	G X A
	ICP-2210A x ICPR-4531	21.18	-0.65	G X A
	ICP-2210A x ICPL-87119	94.65	2.87 *	G X G
Pollen fertility (%)	ICP-2210A x ICPR-4531	94.56	1.97	G X G
	ICP-2098A x ICPL-87119	94.22	1.93	G X G

combining ability effects of the parents involved in the combination for different characters in pigeonpea

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