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Combining Ability, Heterosis and Inbreeding Depression Analysis for Using CMS Lines in Long Duration Pigeonpea

Sandeep Kumar Saroj, Mahendra Narain Singh*, Tejveer Singh

Department of Genetics and Plant Breeding
Institute of Agricultural Sciences
Banaras Hindu University, Varanasi, India
* *mnsbhu@yahoo.co.in*

Abstract: *Evaluation of 26 F_1 hybrids were involving two CMS lines and 13 restorers/testers in line × tester fashion, data recorded on ten agronomical characters. The four cross combinations viz., ICPA 2043 × Azad, ICPA 2043 × ICPR 4105, ICPA 2092 × ICPR 3760 and ICPA 2092 × MA 6, exhibited significantly high SCA effects for seed yield and the parents involved having high × high and low × low GCA effects. The four hybrids viz., ICPA 2043 × Asha, ICPA 2092 × Asha, ICPA 2043 × Azad and ICPA 2043 × ICPR 4105 showed good heterosis, MPH, BPH and EH, over commercial variety i.e. MAL 13 as well as inbreeding depression. Further, two hybrids (ICPA 2043 × Azad and ICPA 2043 × Asha) could manage to out yield the check, MAL 13, significantly with the margin of > 20 % and thus may be exploited for heterosis breeding in pigeonpea.*

Keywords: *Combining ability, Heterosis, Inbreeding depression, Yield and yield traits, pigeonpea*

1. INTRODUCTION

Globally, pigeonpea is cultivated on 4.6 million hectare with an annual production of 3.4 million tonnes and a mean productivity of 780 kg/ha. The total pulse production in India was 17.21 million tonnes from an area of 24.78 million ha and productivity being, 694 kg/ ha, which is still short of the present consumption of ~19 million tonnes and thus forcing the country to import pulses to the tune of 1.5-2.0 million tonnes annually (https://www.agricoop.nic.in, accessed on Feb. 28, 2013). The per capita availability of protein in the country is 28 g/day, while WHO recommended it should be 80 g/day (Saroj et al. 2013), consequently most serious problem of the malnutrition existing among the poor people, where most of the people have vegetarian diet and avoid the animal protein. It is needs fulfil its demand through pulses protein. Therefore, it is necessary to increase the production of pigeonpea, which could be done opting suitable breeding methods.

Combining ability is one of the most effective devices for selection of superior parents for hybridization and provides valuable information regarding crosses combinations to be exploited commercially also. The first investigation of genetic male sterility (Reddy et al. 1978) and the cytoplasmic genetic male sterility (Tikka et al. 1997) used for commercial exploitation of hybrid vigour in pigeonpea crop.

Male sterility systems have also played a great role in enhancing productivity in the various crops through exploitation of hybrid vigour. Through the utilization of GMS system, the world's first pigeonpea (food legume) hybrid, ICPH-8 was released in 1992 by ICRISAT for cultivation in India, which exhibited 25-30% yield advantage over the control at farmer's fields (Saxena et al. 1992). Encouraged from the performance of this hybrid, few more hybrids such as, PPH- 4, by Punjab Agricultural University, Ludhiana, CoH-1, CoH-2, CoH-5 and IPH-732, by TNAU, Coimbatore and AKPH-4101 & AKPH-2022, by Punjabrao Krishi Vidyapeeth, Akola have been released for general cultivation in respective states. However, these GMS based hybrids could not be commercialized because of labour intensive seed production and seed purity as roguing of about 50 per cent fertile plant from the female plot resulted decreased population (Reddy and Faris 1981).

The first stable CMS line for commercial exploitantion could be developed by Tikka et al. 1997, GT-288A with its maintainer, GT-288B utilizing as A_2 cytoplasm source. This cytoplasmic-genic male sterility system contains A line with S (rr), B line with F (rr) and R line with S/F (RR) and consequently, first CGMS based hybrid SKNPH-10 (GTH-1) has been released for cultivation in Gujarat (Majumder**,** 2004). Further, second CMS based hybrid ICPH 2671, showing an yield advantage of 47% over 'Maruti' coupled with resistance to *Fusarium* wilt and sterility mosaic diseases has been released by both a private seed company (as 'Pushkal') and a public sector university (RV ICPH 2671) in 2010 in medium early/early maturity group (Saxena et al. 2013). The utilization of CMS system for the development of commercial hybrids in pigeonpea would be possible of improvement of seed yield by developing hybrids or by selecting transgressive segregants from the crosses showing high heterotic response.

2. MATERIALS AND METHODS

Experimental material consisted of 26 hybrids obtained in line × tester mating design involving two cytoplasmic male sterile (CMS) lines having A_4 cytoplasm (*C. cajanifolius*) viz., ICPA 2043 and ICPA 2092 and 13 testers *viz.*, Asha, Azad, C 11, ICP 12730, ICP 6399, ICP 9149, ICPR 3760, ICPR 3802, ICPR 4105, KA 91-25, LRG 41, MA 6 and NDA 1. The 26 F_1s and their parents were evaluated in a RBD design with three replications and F_2s populations, in two crop seasons 2010-2011 and 2011-12 in Agricultural Research Form of Banaras Hindu University, Varanasi, India. The plot consisted of three row of 4 m length for parents (P_1 and P_2) and $F_{1s,}$ and 15 rows for F_2's, with inter and intra row spacing of 75 × 25 cm, respectively.

Observations were recorded on ten randomly selected plants (excluding the border plants) from parents (P_1 and P_2) and F_1 in each row/replication and 150 fully fertile plants from each F_2 populations for ten quantitative traits *viz*., days to 50% flowering, days to maturity, plant height, number of primary and secondary branches, pods per plant, pod length, seeds per pod, 100-seed weight and yield per plant. The combining ability was estimated using line × tester method described by Kempthorne, 1957, as well as heterosis over mid parent (MP), superior parent or batter parent (BP), standard/economic heterosis (EH) and inbreeding depression (percentage) were measured as per the standard procedures.

3. RESULTS AND DISCUSSION

Table 1. *Analysis of variance for combining ability (Line × Tester analysis including parents)*

Source of Variations	df	Mean Sum of Squares									
		50% Flowering	Maturity	Plant Height	Primary Branch	Secondary Branch	Pods/ Plant	Pod Length	Seed / Pod	100 Seed weight	Yield/ Plant
Replication	2	5.32	11.13	3.11*	500.18	76.63**	4.17	99.44	0.08	0.027	0.11
Genotypes	40	34.81**	47.14**	1564.17**	74.63**	208.36**	4403.12**	0.79**	0.11**	1.63**	133.98**
Crosses	25	34.85**	50.29**	1528.09**	79.68**	254.55**	4621.80**	0.71**	0.11**	1.27**	154.28**
Parents	14	13.87**	14.44**	1516.06**	69.72**	57.23**	947.48**	0.89**	0.09**	2.31**	50.31**
Parents Vs. Hybrids	1	326.95**	426.46**	334.59**	12591.62**	16.93	1169.29**	47314.65**	1.49**	0.19**	1.10**
Line	1	91.54	343.69**	1528.08	355.93	35.07	8606.22*	0.81	0.03	5.14**	576.10**
Testers	12	33.11	52.58	965.47	53.68	306.30	7756.09**	0.68	0.11	1.76*	235.36**
Lines × Testers	12	31.87**	23.54**	1302.96**	82.67**	221.10**	1155.48**	0.73**	0.13**	0.46**	38.04**
Error	80	5.25	4.67	197.88	7.89	221.1	184.9	0.06	0.02	0.06	5.40

**, ** Significant at P =0.05 and P = 0.01, respectively*

The analysis of variance (Table 1) revealed highly significant differences among the parents and hybrids for all of the yield traits indicating large parental diversity. The estimates of components of variances viz., σ^2 Female (Line) and σ^2 Male (Tester) and their interactions σ^2gca and σ^2sca for ten characters were depicted in table 2. The ratio of σ^2gca : σ^2sca indicated that the σ^2sca were grater in magnitude for days to 50% flowering, plant height, number of primary and secondary branches, pod length and seeds per pod, indicating the prevalence of non additive gene action governing these traits while rest traits were under the control of additive gene action.

Table 2. *Estimates of components of variances and degree of dominance*

Component	Days to 50% flowering	Days to maturity	Plant height	No. of Primary branches	No. of Secondary branches	Pods per plant	Pod length	Seeds per Pod	100 Seed weight	Seed yield per plant
σ^2 Female (Lines)	2.21	8.69**	34.11	8.92	0.47	215.93*	0.02	0.00	0.13**	14.63**
σ^2 Male (Testers)	4.64	7.98	127.93	7.63	48.29	1261.87**	0.10	0.01	0.28*	38.32**
σ^2 gca	2.54*	8.60**	46.62	8.75*	6.85	355.39**	0.03	0.00	0.15**	17.79**
σ^2 sca	8.87**	6.29**	368.36**	24.93**	68.18	323.52**	0.22*	0.04	0.13**	10.88**
σ^2 gca /σ^2 sca	0.29	1.37	0.13	0.35	0.10	1.10	0.14	0.00	1.15	1.64
σ^2 A	5.07	17.20	93.24	17.50	13.70	710.78	0.06	0.00	0.30	35.58
σ^2 D	8.87	6.29	368.36	24.93	68.18	323.52	0.22	0.04	0.13	10.88
$\sqrt{\sigma^2 D/\sigma^2 A}$	1.32	0.60	1.99	1.19	2.23	0.67	1.91	4.15	0.66	0.55
h^2 (narrow sense)%	32.32	68.66	17.67	38.84	15.68	64.86	20.16	8.89	66.45	73.73
GA 5%	2.64	7.08	8.36	5.37	3.02	44.23	0.23	0.04	0.92	10.55
Genetic Advance as % of mean	2.46	3.01	5.15	43.75	20.25	23.57	5.17	1.22	9.16	29.14

**, ** Significant at P =0.05 and P = 0.01, respectively*

The actual estimates of component of variance i.e. additive (σ^2A) and dominance (σ^2 D) were worked out from combining ability analysis of variance for all the traits. The estimates of σ^2A was greater than the σ^2D for days to maturity, pods per plant, 100-seed weight and seed yield per plant indicating the greater importance of additive component of gene action for the inheritance of these traits. However, for rest of the traits (days to 50 % flowering, plant height, number of primary and secondary branches, pod length and seeds per pod), the σ^2D components were higher than σ^2A, indicating the preponderance of dominance component of gene action for the expression of these traits. This kinds of gene action has also been observed by Shoba and Balan, 2010; Parmar *et al*. 2012. However, others (Sidhu et al. 2000; Thiruvengadam and Muthiah, 2012) have also realized the importance of both additive and non-additive gene effects for the inheritance of these traits.

The nature and magnitude of gene actions as observed in present study can provide a crucial guideline in deciding the breeding methodologies for improvement of this crop. The conventional breeding procedure like synthetic and pedigree method mostly exploits the proportion of genetic variability, which is due to the additive and additive × additive type of gene actions. Adoption of specific population improvement schemes such as biparental mating or recurrent selection might be an effective method over conventional approaches of breeding, as it utilizes other gene effect as well.

Narrow sense heritability revealed in high magnitude of the four traits *viz.,* days to maturity, pods per plant, 100-seed weight and seed yield per plant. High genetic advance as per cent of mean was observed for four traits, number of primary and secondary branches, pods per plant and seed yield per plant. Earlier workers (Linge et al. 2010; Sreelakshmi et al. 2011; Saroj et al. 2013) also reported similar result for narrow sense heritability and genetic advance.

Based on the significant values recorded through analysis of variance for combining ability, the estimates of GCA effects of 15 parents (two lines and 13 testers) for only four characters namely, days to maturity, pods per plant, 100-seed weight and seed yield per plant are presented in table 3. The GCA effects of the six parents, ICPA 2043, Asha, Azad, ICP 9149, ICPR 4105 and KA 91-25 were revealed positively significant for seed yield per plant. Only ICPA 2043 exhibited good general combiner for days to maturity, pods per plant and 100 seed weight. Among the testers, Asha have positive effect for pods per plant, 100 seed weight and negatively desirable for days to maturity. Azad showed positive GCA effect for pods per plant only. The ICP 9149 revealed negative and positive GCA effect for days to maturity and pods per plant, respectively. ICPR 4105 exhibited positive GCA effect for pods per plant and negative GCA effect for days to maturity and KA 91-25 was displayed good combiner for 100-seed weight. Aforesaid parents exhibited good GCA effects for these explain traits under study, the lines ICPA 2043 and testers Asha, Azad, ICP 9149, ICPR 4105 and KA 91-25 may be given importance in the choice of parents based on the overall GCA effects. Multiple crosses using the above parents can be attempted breeding programme for improvement of seed yield.

Table 3. *Estimates of general combining ability effects for 15 patents from a Line × Tester design in respect of four traits in pigeonpea*

Parents	Days to Maturity	Pods/ Plant	100 Seed Weight	Seed yield/Plant
Lines				
ICPA 2043	-2.1**	10.50**	0.26**	2.72 **
ICPA 2092	2.10 **	-10.5**	-0.26**	-2.72**
S.E(gi) Lines ±	0.35	2.18	0.04	0.37
S.E(gi-gj) Lines ±	0.49	3.08	0.06	0.53
C.D. at 0.05%	0.98	6.19	0.11	1.06
C.D. at 0.01%	1.31	8.26	0.15	1.41
Testers				
Asha	-2.25 *	54.81**	0.66**	11.07 **
Azad	-1.51	63.24**	0.12	10.93 **
C 11	2.81 **	16.05**	-0.58**	1.51
ICP 12730	-0.25	-17.24 **	-0.21 *	-2.65 **
ICP 6399	-0.12	-24.37**	0.11	-2.17 *
ICP 9149	-4.31**	15.96**	-0.19	2.82 **
ICPR 3760	-2.97	-45.36**	0.34**	-7.8**
ICPR 3802	6.66**	-46.31**	0.16	-7.56**
ICPR 4105	-2.92 **	20.72**	0.13	3.51 **
KA 91-25	2.79 **	2.58	1.05**	2.43 *
LRG 41	1.12	16.53**	-0.86**	-2.11 *
MA 6	0.54	-45.51**	-0.8**	-7.84**
NDA 1	0.40	-11.09	0.08	-2.14 *
S.E(gj) Testers ±	0.88	5.55	0.10	0.95
S.E(gi-gj) Testers ±	1.25	7.85	0.14	1.34
C.D. at 0.05%	2.51	15.77	0.29	2.69
C.D. at 0.01%	3.34	21.02	0.38	3.59

**, ** Significant at P =0.05 and P = 0.01, respectively*

Similarly, observed that few parents were good general combiners for yield and certain yield traits whereas other parents were identified as a desirable general combiners for few yield components only (Shoba and Balan, 2010; Parmaar et al. 2012; Thiruvengadam and Muthiah, 2012).

From these observations, it may be concluded that single, three way or even complex crosses involving ICPA 2043, Asha, Azad, ICPR 4105, KA 91-25 and ICP 9149 lines or materials may be handled through inter-mating and superior lines/genotypes can be selected in early segregating generations i.e. F_2, a sort of population improvement approach would be more efficient for isolating desirable segregants in advanced generations.

The estimate of SCA effects of the hybrids are presented in table 4. The hybrid, ICPA 2043 × Azad had been revealed superiority of SCA effects for three traits *viz*., pod length, pods per plant and seed yield per plant. The cross combinations ICPA 2043 × ICPR 4105 exhibited good SCA effects for most of the yield traits *viz*., plant height, pod length, seeds per pod, pods per plant, primary and secondary branches along with the seed yield per plant. Hybrid, ICPA 2092 × ICPR 3760 for three traits (pod length, seeds per pod and seed yield per plant) and pods per plant as well as seed yield per plant were found good SCA effects in the hybrid ICPA 2092 × MA 6.

Table 4. *Estimates of specific combining ability effects for 26 crosses of ten traits*

Hybrids	Day to 50% Flowering	Days to Maturity	Plant Height cm	Pod Length cm	Seeds / Pod	Pods/ Plant	Primary Branches	Secondary Branches	100 Seed Weight	Yield/ Plant
ICPA 2043 × Asha	4.51 **	-0.54	-20.25 *	0.11	-0.01	-12.42	-8.31**	-4.44	0.16	-0.95
ICPA 2043 × Azad	-2.18	0.42	-15.42	0.39 **	-0.10	17.46 *	-0.98	-8.96**	-0.04	3.04 *
ICPA 2043 × C 11	1.58	0.39	2.04	-0.06	0.04	-9.71	0.69	7.49 **	-0.16	-1.46
ICPA 2043 × ICP 12730	1.81	-0.22	-15.08	-0.18	0.20 *	-3.62	-2.09	-1.29	0.48 **	1.18
ICPA 2043 × ICP 6399	-1.25	0.99	-20.43 *	-0.10	0.07	3.89	-3.27 *	-1.80	-0.29	0.56
ICPA 2043 × ICP 9149	-1.29	-1.40	-8.84	-0.05	0.06	-3.09	-2.43	-3.56	0.24	0.41
ICPA 2043 × ICPR 3760	2.18	-0.34	5.47	-0.72**	-0.33 **	-0.77	1.87	-3.68	-0.10	-3.54 *
ICPA 2043 × ICPR 3802	-0.27	-4.42**	17.25 *	-0.3 *	-0.01	8.47	3.62 *	0.59	-0.24	0.22
ICPA 2043 × ICPR 4105	-0.04	0.21	20.35 *	0.72 **	0.25 **	17.59 *	5.55 **	12.29**	-0.55**	3.11 *
ICPA 2043 × KA 91-25	-4.38 **	4.15 **	5.67	-0.01	0.03	-10.11	2.48	2.41	0.15	-0.33
ICPA 2043 × LRG 41	0.48	1.00	20.462*	-0.11	-0.09	9.11	4.356 **	8.30 **	0.22	1.09
ICPA 2043 × MA 6	0.97	1.54	3.94	0.33 *	-0.04	-30.89 **	-0.45	-2.70	-0.08	-5.72 **
ICPA 2043 × NDA 1	-2.11	-1.78	4.84	-0.03	-0.08	14.09	-1.05	-4.65	0.21	2.39
ICPA 2092 × Asha	-4.51 **	0.54	20.25*	-0.11	0.01	12.42	8.31 **	4.44	-0.16	0.95
ICPA 2092 × Azad	2.18	-0.42	15.42	-0.39 **	0.10	-17.46 *	0.98	8.96 **	0.04	-3.04 *
ICPA 2092 × C 11	-1.58	-0.39	-2.04	0.06	-0.04	9.71	-0.69	-7.49 **	0.16	1.46
ICPA 2092 × ICP 12730	-1.81	0.22	15.08	0.18	-0.2 *	3.62	2.09	1.29	-0.48 **	-1.18
ICPA 2092 × ICP 6399	1.25	-0.99	20.43 *	0.10	-0.07	-3.89	3.27*	1.80	0.29	-0.56
ICPA 2092 × ICP 9149	1.29	1.40	8.84	0.05	-0.06	3.09	2.43	3.56	-0.24	-0.41
ICPA 2092 × ICPR 3760	-2.18	0.34	-5.47	0.72 **	0.33 **	0.77	-1.87	3.68	0.10	3.54 *
ICPA 2092 × ICPR 3802	0.27	4.42 **	-17.25 *	0.30 *	0.01	-8.47	-3.62 *	-0.59	0.24	-0.22
ICPA 2092 × ICPR 4105	0.04	-0.21	-20.35 *	-0.72**	-0.25 **	-17.59 *	-5.55 **	-12.29**	0.55 **	-3.11 *
ICPA 2092 × KA 91-25	4.38 **	-4.15 **	-5.67	0.01	-0.03	10.11	-2.48	-2.41	-0.15	0.33
ICPA 2092 × LRG 41	-0.48	-1.00	-20.46 *	0.11	0.09	-9.11	-4.36 **	-8.3**	-0.22	-1.09
ICPA 2092 × MA 6	-0.97	-1.54	-3.94	-0.33 *	0.04	30.89 **	0.45	2.70	0.08	5.72 **
ICPA 2092 × NDA 1	2.11	1.78	-4.84	0.03	0.08	-14.09	1.05	4.65	-0.21	-2.39
S.E.(S_{ij})	1.32	1.25	8.12	1.62	2.35	7.85	0.14	0.08	0.14	1.34
S.E.(S_{ij}-S_{kl})	1.87	1.76	11.48	2.29	3.32	11.10	0.19	0.12	0.20	1.90
C.D. at 0.05%	3.76	3.54	23.07	4.61	6.67	22.30	0.39	0.23	0.41	3.81
C.D. at 0.01%	5.00	4.73	30.76	6.41	8.90	29.73	0.51	0.31	0.54	5.08

**, ** Significant at P =0.05 and P = 0.01, respectively*

Out of 26, only four hybrids, ICPA 2092 × MA 6 (5.72), ICPA 2092 × ICPR 3760 (3.54), ICPA 2043 × ICPR 4105 (3.11) and ICPA 2043 × Azad (3.04) exhibited positively significant SCA effects and thus could be the most desirable cross combinations for seed yield as well as few yield traits.

Another avenue for exploitation of high SCA effects would be in cross combination where the F_1 means are superior to the best local variety or at least best parental variety. Such crosses are desirable for selecting the promising segregates, as SCA effects in such crosses would probably be mostly due to additive × additive type of gene interaction, which are fixable.

Among the hybrid combinations, ICPA 2043 × Azad, ICPA 2043 × ICPR 4105, ICPA 2092 × ICPR 3760 and ICPA 2092 × MA 6 might be expected for the improvement of respective traits as found to be desirable genes for most of the characters studied (Table 5). Amarnath and Subrahmanyam (1992) suggested that crosses with high SCA effects could be much useful if high GCA of the parents involved accompanied them.

Table 5. *Four good heterotic cross combinations (specific combiner) for seed yield per plant and their performance for other traits*

Crosses with maximum *SCA* effects	Mean seed yield/plant (g)	SCA effects	GCA effects of parents		Cross combination	Significant response in related characters for SCA effects
			P_1	P_2		
ICPA 2043 × Azad	54.83	3.04*	2.72**	10.94**	high × high	Seed yield per plant, Pod per plant, Pod length
ICPA 2043 × ICPR 4105	47.47	3.11*	2.72**	3.51**	high × high	Seed yield per plant, Pod per plant, pod length, seeds per pod, primary and secondary branches
ICPA 2092 × ICPR 3760	31.16	3.54*	-2.72**	-7.80**	low × low	Seed yield per plant, pod length, seeds per pod
ICPA 2092 × MA 6	33.30	5.72**	-2.72**	-7.84**	low × low	Seed yield per plant, pods per plant

*, ** *Significant at P =0.05 and P = 0.01, respectively*

From the investigation, it may not be necessary that two good and tow poor general combiners get high × high and low × low cross combinations.

Four crosses *viz.*, ICPA 2043 × Asha, ICPA 2092 × Asha, ICPA 2043 × Azad and ICPA 2043 × ICPR 4105 were identified as the best cross combinations as they revealed significant heterosis in desirable direction over the standard check, MAL 13 and only these crosses explained further (table 6). These hybrids may be used for commercial exploitation of the heterosis for seed yield. However, out of four, only two hybrids (ICPA 2043 × Azad and ICPA 2043 × Asha) could manage to out yield the check, MAL 13, significantly with the margin of > 20% and thus may be exploited for heterosis breeding in this important pulse crop of our country. Perhaps, aforesaid of the crosses revealed significant heterosis over mid-parent, better parent as well as economic heterosis for seed yield indicating the presence of non additive gene interaction (dominance and epistasis). The *per se* performance of these hybrids were recorded maximum ranged from 54.83 in ICPA 2043 × Azad followed by 50.97, 47.47, 47.44 in ICPA 2043 × Asha, ICPA 2043 × ICPR 4105 and ICPA 2092 × Asha, respectively. The maximum better parent heterosis was recorded in the cross ICPA 2043 × Azad (41.30) followed by ICPA 2043 × Asha (40.85), ICP A 2043 × ICPR 4105 (33.58) and ICPA 2092 × Asha (31.10) respectively. The similar results reported by Saxena *et al.* (2010), in the traits of CMS based hybrid ICPH 2671, which 28.4% yield superiority over local check in farmer field. Hybrid ICPH 2671 recorded 47% superior over the control variety of "Maruti" in multi-location station trials for 4 year for seed yield and 46.5% mean yield greater than that "Maruti", recorded in five Indian states (Saxena et al. 2013).

Table 6. *Good four crosses on the basis of per se performance and heterosis (%) for seed yield (g)*

Crosses	*Per se* performance	Heterosis (%)		
	F_1 hybrids	BP	MP	EH
ICPA 2043 × Asha	50.97	40.85**	42.12**	20.53 **
ICPA 2092 × Asha	47.44	31.10**	36.43**	12.18 **
ICPA 2043 × Azad	54.83	41.30**	47.51**	29.66 **
ICPA 2043 × ICPR 4105	47.47	33.58**	34.33**	12.25 **

*, ** *Significant at P =0.05 and P = 0.01, respectively*

The heterosis for seed yield recoded positively significant superiority over MP and Standard check, respectively. Heterosis for seed yield over MP ranged from 34.33 (ICPA 2043 × ICPR 4105) to 47.51% (ICPA 2043 × Azad) and over check from 12.18 (ICPA 2092 × Asha) to 29.66 (ICPA 2043 × Azad). The findings of similar nature were also reported by Gupta et al. (2011), Wanjari and Rathod (2012) in the same crop.

The hybrids *viz.,* ICPA 2043 × Asha, ICPA 2043 × Azad and ICPA 2043 × ICPR 4105 play to be promising in desirable direction for seed yield and its components. These crosses could be considered for exploitation of hybrid vigour with cytoplasmic male sterile lines in pigeonpea.

In the present study, the heterotic hybrids for seed yield exhibited significant inbreeding depression in F_2 generation (Table 7). The magnitude of inbreeding depression varied for seed yield from 18.79 (ICPA 2043 × Azad) to 35.34 (ICPA 2043 × ICPR 4105) per cent which might be due to wide base of genetic material in all these crosses. The positive inbreeding depression indicated the presence of dominance effects for most of the traits. Association of high heterosis with inbreeding depression for seed yield per plant and some of its component traits were observed by Kumar et al. (2002) and Kumar et al. (2012) in the same crop. Inbreeding depression in relation to seed yield of the corn, showed the variation from 27.6% to 59.13%, suggested by Oliveira et al. (2012). Rodrigues et al. (2001) confirmed that, high inbreeding depression kept high genetic relationship to an ancestor. Where, it may be used for heterosis exploitation through *line breeding*.

Table 7. *Summary of desirable heterotic effect and estimates of inbreeding depression in F2s from F1s for four crosses for yield and ten yield traits*

Crosses		Days to 50% Flowering	Days to maturity	Plant height (cm)	Primary branches	Secondary branches	Pods/plant	Pod length (cm)	Seed/pod	100 seed weight (g)	Yield/plant (g)
ICPA 2043 × Asha	H	-	**	-	**	-	**	-	-	-	**
	ID	-2.08	-6.45 **	17.37	-59.3 *	-30.93	16.42	0.39	4.82	6.84 **	20.51*
ICPA 2092 × Asha	H	**	-	**	**	-	**	-	-	-	**
	ID	-1.58	-0.88	35.22 **	70.75*	69.43*	40.42**	3.87	0.83	1.86 *	34.73**
ICPA 2043 × Azad	H	**	**	-	-	-	**	-	-	**	**
	ID	-5.36 *	-3.11 *	3.02	6.09	-15.21	21.60**	9.96	2.83	-5.27 **	18.79**
ICPA 2043 × ICPR 4105	H	**	**	**	*	**	**	-	*	**	**
	ID	7.34*	-4.43 **	14.7	19.37	72.50**	28.10*	11.99*	17.35*	4.83 *	35.34**

**, ** Significant at P =0.05 and P = 0.01, respectively*

H: Heterosis; ID: Inbreeding Depression

In general, the crosses, which showed better performance in F_1, low/even negative inbreeding depression in F_2 and involved parents with high *per se* performance and significantly positive GCA effects, would be more useful in producing high yielding pure lines. Such crosses were ICPA 2043 × Azad and ICPA 2043 × ICPR 4105 which had maximum economic heterosis involving parent with high GCA effects. The increased vigour in such crosses is expected to be mainly due to accumulation of favourable additive genes and complementary epistasis, the fixable gene effects. Such crosses are expected to throw desirable segregants that may be handled through pedigree method and suitable varieties may be released.

On the other hand there are few crosses (ICPA 2092 × ICPR 3760 and ICPA 2092 × MA 6) showing higher magnitude of heterotic effects, were also associated with higher inbreeding depression. In such cases, high degree of heterosis in F_1 and significant inbreeding depression in F_2 could be attributed to high magnitude of non-additive gene effects controlling the traits.

In addition, several crosses showed negative estimates of inbreeding depression for seed yield and its components indicating thereby the existence of transgressive segregants for respective traits. In such crosses, intensive selection should be practised in large segregating populations for isolating several high yielding homozygous lines.

4. Conclusions

The concept of combining ability is a major landmark in understanding the genetic architecture of populations and in planning breeding programmes. It helps in choosing the parents for hybridization for isolating desirable recombinants in advanced generations or for using in heterosis breeding. The hybrid breeding programme in several crops is primarily based on the concept of specific combining ability. The development of synthetics and composites also aims for exploiting general combining ability (fixable component of genetic variance) and to some extent the specific combining ability effects (non-fixable gene effects).

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