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Delineating Frequency of Heterotic Hybrids for Yield and its Attributing Traits in Cowpea [*Vigna unguiculata* (L.)] Cross Combinations

Hemal K. Parmar[1], Manish Sharma[2], P.R. Patel[2], N.V. Soni[1], H.N. Zala[1], Tejaswini Banakar[1], Vishakha Patel[1]

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ABSTRACT

Background: Cowpea, popularly known as lobia (*Vigna unguiculata* L.) is a crucial pulse crop in the fight against hunger in underdeveloped nations. However, yield of cowpea is low just like other pulses and therefore, concentrated efforts are needed to increase its yield. Examining the genetic architecture of yield and the contributing features is necessary to enhance its productivity.

Methods: Prsesnt study was conducted in cowpea in order to comprehend gene action and assess the predictability of frequency of heterotic hybrids based on parental gca effects. The 21 F_1s effected using 7 lines and 3 testers were evaluated along with their parents for nine productivity *per* se traits. Each parent's overall gca status (high or low), as well as each hybrid's overall sca and heterotic status (high or low) across nine attributes, were ascertained.

Result: Lines, PL 4, PGCP 12 and tester PL 7 registered as good general combiners and cross GC 7 × GC 4 recorded high mean seed yield heterotic effect along with positive significant sca effect for seed yield per plant and its component characters. The perusal of *per se* performance as well as heterotic effect of crosses revealed that, the cross PL 4 × PL 7 was best for seed yield and its component traits. Among hybrids, ten (47.61%) and eight (38.09%) crosses were classified as having high (H) overall sca and heterotic status, respectively and remaining were classified as having low (L) overall sca and heterotic status. Furthermore, no inferences could be established regarding the frequency of heterotic hybrids based on gca effects because heterotic hybrids for productivity per se traits might be produced by parents with high, low, or contrasting gca effects in cowpea.

Key words: Cowpea, Combining ability, Heterosis, Pulses.

INTRODUCTION

Cowpea, commonly referred to as *lobia Vigna unguiculata* L., is an important *kharif* pulse crop that is grown in North and South America, Africa, India and other countries primarily as a grain but also as a vegetable and fodder crop. It is a popular grain legume that serves as a versatile, drought-tolerant, nitrogen-fixing crop and is a great source of affordable protein (Kamara *et al.,* 2010 and Sharma *et al.,* 2022). The cowpea seeds contain 23% protein, 50-67% carbohydrate, 1.0% fat and 3.8% fibre and also contain some micronutrients such as iron and zinc. Compared to cereal grains, the protein in cowpea seeds is higher in amino acids like lysine and tryptophane. Vitamin C is present in good amounts in germinated cowpea seeds (Clark, 2007). Cowpea leaves are a nutrient-dense food source that are low in fat and sodium and high in potassium, digestible and non-digestible carbohydrates, and protein and minerals (Kamara *et al.,* 2010). In India, it is cultivated mainly in Rajasthan, Maharashtra, Karnataka, Gujarat, Tamil Nadu, Andhra Pradesh and Madhya Pradesh. Worldwide cowpea occupied 14.9 million hectares area with production of 8.9 million tonnes (FAOSTAT, 2022) indicating low productivity of this crop worldwide. Heterosis breeding is the ideal strategy for maximising crop's productivity potential if the creation of F_1 hybrids is both technically and financially possible (Sharma and Shadakshari, 2021 and Gandhi *et al.,* 2024a). Novel yields in a number of crops, including self-pollinated and frequently cross-pollinated species, have been made possible by heterosis breeding. Similar to any other crop, the use of heterosis to increase productivity in grain legumes is dependent on three main factors: the degree of heterosis, the viability of producing hybrid seeds on a large scale and the type of gene action involved. These factors are all influenced by the genetic backgrounds of the

[1]Department of Genetics and Plant Breeding, C.P. College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar-385 506, Gujarat, India.
[2]Pulses Research Station, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar-385 506, Gujarat, India.

Corresponding Author: Manish Sharma, Pulses Research Station, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar-385 506, Gujarat, India.
Email: manisharmagpb@sdau.edu.in

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parents involved in the breeding program (Boraiah *et al.,* 2019). In self-pollinated crops, varietal development entails hybridization using various mating designs and selections in segregating generations. The resulting advanced generations are then assessed for yield and associated characteristics for use as breeding material (Sharma and Sridevi, 2016; Patel *et al.,* 2021a and Parmar *et al*., 2024). In this case, the most important stage in the hybridization process is selecting parents who will produce a high frequency of heterotic hybrids. Using a high-performance genotype for selection following hybridization may not always result in superior hybrids and transgressive segregants (Sharma *et al*., 2022a). If grown in diverse environmental conditions, the genotypes' potential for yield will be significantly impacted (Patel *et al*., 2021b and Sharma *et al*., 2025). Different types of breeding designs, like diallel, test crosses, bi-parental, line × tester and multiplecrosses, are used to evaluate breeding material. Evaluating the effects of GCA and SCA on parental lines, SCA and heterosis of crosses and trait heredity is the main objective of these designs (Sharma and Shadakshari, 2021 and Gandhi *et al.,* 2024b). One of the factors taken into consideration when selecting parents to produce a higher frequency of heterotic hybrids is combining ability (CA). The prediction of hybrid's performance is where practical value of CA rests (Griffing, 1956). Not only does CA offer an unbiased criteria for selecting parents, but it also offers helpful hints on the method of action of the genes governing features that are economically significant. Using experimental data from cowpea, an attempt was made, under these assumptions, to derive a criteria based on gca values for selecting parents in order to create a high frequency of heterotic hybrids.

MATERIALS AND METHODS

Experimental material and design

The present study was carried out during the summer of 2023 and the *Kharif* of 2023-24 at the Pulses Research Station, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat, India. The experimental material chosen for this study consisted of the seven genotypes designated as lines (GC 3, GC 7, PGCP 6, JLS 60, EC 723909, EC 724035 and PL 4) crossed with three testers (PGCP 12, PL 7 and GC 4) during 2023 summer season following Line × Tester mating design (Kempthorne, 1957). Twenty one F1s and 10 parents (Table 1) were evaluated in randomized complete block design with three replications during 2023-24 *Kharif* season. Each entry was sown in a single row of 4 m length with a spacing of 0.45 m between rows and 0.10 m between plants within a row. Recommended agronomic and plant protection practices were followed during the crop growth period to raise a healthy crop.

Table 1: List of genotypes used as parents.

Genotypes name	100-Seed weight (g)	Seed colour	Seed class	Salient features
GC 3	14.16	Cream	Medium	Nationally adapted, early maturing and high yielding, short statured growth, pods are moderate in size, drought tolerant and disease resistant.
GC 7	10.26	Brown	Small	Early maturity, high yielding variety.
PGCP 6	7.60	Brown	Small	Resistant to YMV and bacterial blight, bushy type.
JLS 60	12.23	Greenish brown	Medium	Resistant to wilt, YMV and pod-borer, and lodging resistant due to dwarf in stature.
EC 72 3909	9.96	Black	Small	Early flowering, erect type plant.
EC 724035	10.90	Yellowish white	Small	White coloured flowers, dwarf and bushy.
PL 4	12.80	White	Medium	It has tolerance to major bacterial and viral diseases like yellow mosaic, photo. insensitive and drought tolerant.
PGCP 12	14.46	Tan	Medium	It is tolerant to aphid thrips bruchids and resistant to CYMV, Protein 23 to 25%.
PL 7	14.73	Black-white	Medium	Protein content 27% and resistant to yellow mosaic.
GC 4	11.96	White	Medium	Early, Synchronous maturity, moderately resistant to CYMV.

Source: Pulses Research Station, SDAU, Sardarkrushinagar (Gujarat).

Table 2: Analysis of variance for combining ability and estimates of component of variance for different characters in cowpea

Source of variation	d.f.	Days to flowering	Days to maturity	Number of branch	Plant height	Number of pod per plant	Number of seed per pod	Pod length	Seed yield per plant	100 seed weight
Replications	2	0.90	4.42	0.21	4.56	7.23	1.43	0.40	14.95	0.88
Crosses	20	44.64**	61.14**	0.95**	337.98**	211.22**	11.85**	12.05**	385.93**	24.18**
Lines	6	72.99	45.47	1.55	497.20*	180.94	11.24	19.54*	447.57	44.91*
Testers	2	32.90	161.33	1.14	1020.13**	357.76	13.68	28.50*	583.06	33.07
Lines × Testers	12	32.42**	52.87**	0.62**	144.68**	201.94**	11.85**	5.56**	322.25**	12.34**
Error	40	2.85	4.62	0.05	7.75	11.37	0.53	0.39	19.96	0.36
				Estimates of variance component						
σ^2gca		0.31*	0.23*	0.08*	5.03**	0.24	-0.01	0.16**	1.65*	0.30**
σ^2sca		9.85**	15.88**	0.19**	45.64**	63.52*	3.77**	1.72**	100.76**	3.99**
σ^2gca/σ^2sca		0.03	0.01	0.42	0.11	0.01	0.00	0.09	0.02	0.07

*, ** Significant at 5 and 1 per cent levels of significance respectively.

Collection of data and statistical analysis

Data were recorded on five randomly selected plants in each of the 21 F_1s and 10 parents and in each replication on nine productivity *per se* traits *viz*., days to flowering, days to maturity, number of primary branch per plant, plant height, number of pod per plant, number of seed per pod, pod length, seed yield per plant and 100 seed weight. The data were compiled for analysis of the variance of different traits and combining ability was analyzed as method suggested by Kempthorne (1957) using TNAUSTAT software (Manivannan, 2014). The traits means of three replications were used for statistical analysis. General combining ability (gca) effects of 3 testers and 7 lines and specific combining ability (sca) effects of 21 F_1 hybrids and variances due to gca and sca effects were estimated (Kempthorne, 1957). For each of the nine traits, the better parent heterosis (BPH) of 21 F_1 hybrids was assessed. Given that quantitative features might have positive or negative correlations, it is common to find that, for a given parent and hybrid, gca effects, sca effects and BPH, respectively, point in the desired direction. Hence, the overall status of parents with respect to their gca effects and the hybrids with respect to their sca effects and BPH across traits were determined. Crosses were divided into three categories based on the overall gca status of the parents: HH (both parents in a cross with high overall gca status), HL/LH (one parent with high and the other parent with low overall gca status) and LL (both parents with low overall gca status).

RESULTS AND DISCUSSION

Analysis of variance

An analysis of variance for combining ability showed that, for plant height, pod length and 100 seed weight, the mean square due to lines was significant; on the other hand, the mean square due to testers was significant for plant height and pod length (Table 2). For every character, the mean sum of square resulting from crosses and the line × tester interaction were significant, suggesting that the

Table 3: Desirable general combiners for productivity per se traits in cowpea.

Traits	Parents (L/T)	gca effect
Days to flowering	PL 4 (L)	-5.27**
	PL 7 (T)	-0.90*
Days to maturity	PL 4 (L)	-3.49**
	PGCP 12 (T)	-1.05*
	PL 7 (T)	-2.10**
Number of primary branch per plant	PL 4 (L)	0.81**
	PL 7 (T)	0.20**
Plant height	JLS 60 (L)	-9.07**
	EC 72 3909 (L)	-1.98*
	EC 724035 (L)	-5.42**
	PL 4 (L)	-3.20**
	PGCP 12 (T)	-2.23**
	PL 7 (T)	-5.58**
Number of pod per plant	GC 3 (L)	3.22**
	PL 4 (L)	6.97**
	PGCP 12 (T)	3.18**
	PL 7 (T)	1.49*
Number of seed per pod	PGCP 6 (L)	0.50*
	JLS 60 (L)	0.93**
	PL 4 (L)	0.92**
	PGCP 12 (T)	0.71**
Pod length	GC 3 (L)	0.73**
	PGCP 6 (L)	0.94**
	PL 4 (L)	1.98**
	PGCP 12 (T)	0.62**
	PL 7 (T)	0.72**
Seed yield per plant	JLS 60 (L)	7.04**
	PL 4 (L)	5.63**
	PL 7 (T)	4.03**
100 seed weight	EC 72 3909 (L)	0.63**
	EC 724035 (L)	2.47**
	PL 4 (L)	2.38**
	PGCP 12 (T)	1.24**

*, **Significant at 5% and 1% level, respectively. L- Line; T- Tester.

experimental material was very variable and that heterosis breeding may potentially improve the many qualities that were being studied. A review of the variance ratio (σ^2 gca/ σ^2 sca) revealed that non-additive genetic variance predominated for all features, with a ratio less than unity. It therefore highlights the application of the heterosis breeding strategy to maximise the crop's potential vigour. These results were in concordance with the result of Verma *et al.* (2020); Debbarma *et al.* (2022) and Parmar *et al.* (2025).

Trait-wise parental gca effects and hybrid sca and heterosis

Variations in the frequency of genes that are passed down to the progeny with the additive effects account for the variations in gca effects. Line, PL 4 and tester, PL 7 were found good general combiner for all the characters having high gca effect (Table 3). Lines, JLS 60, EC 72 3909 and EC 724035 were good general combiner for plant height and 100 seed weight. Tester, PGCP 12 was good general combiner for days to maturity, plant height, number of pod per plant, number of seed per pod, pod length and 100 seed weight. Given that gca effects are a result of additive and additive × additive gene effects, the parents listed above have a good chance of yielding their respective characters and could be used in a multiple crossing programme to create a dynamic population that can accumulate most of the favourable genes.

The hybrids varied greatly for their sca effects, just as they did for lines and testers for gca effects (Table 4). The preferred specific combiners for all the features, with the exception of days to flowering, number of pods per plant, number of primary branches per plant and 100 seed weight, were GC 7 × GC 4, GC 3 × PL 7 and EC 724035 × PGCP 12. The JLS 60 × PL 7 hybrid was a preferred combination for days to maturity, number of pods per plant and length of

Table 4: Desirable specific combinations based on sca effect and better parent heterosis (BPH) for productivity *per se* traits in cowpea.

Traits	Crosses	sca effect	Crosses	Estimates of BPH
Days to flowering	GC 7 × GC 4	-5.10**	PL 4 × PL 7	-15.92**
	GC 3 × PL 7	-2.65**	PL 4 × PGCP 12	-12.40**
Days to maturity	GC 7 × GC 4	-6.92**	EC 724035 × PGCP 12	-11.28**
	EC 724035 × PGCP 12	-4.73**	GC 3 × PL 7	-10.94**
	JLS 60 × PL 7	-4.35**	PL 4 × PGCP 12	-10.47**
	GC 3 × PL 7	-3.57**	JLS 60 × PL 7	-10.42**
Number of primary branch per plant	PGCP 6 × GC 4	0.77**	PL 4 × PL 7	28.89**
	GC 3 × PL 7	0.56**	PL 4 × PGCP 12	25.18**
	EC 724035 × PGCP 12	0.34*	GC 3 × PL 7	21.97**
Plant height	GC 7 × GC 4	-9.63**	GC 7 × GC 4	-9.07**
	PGCP 6 × PL 7	-6.97**		
	GC 3 × PL 7	-5.93**		
Number of pod per plant	GC 7 × GC 4	13.09**	PL 4 × PGCP 12	80.97**
	EC 724035 × PGCP 12	8.07**	PL 4 × PL 7	62.79**
	JLS 60 × PL 7	6.38**	EC 724035 × PGCP 12	51.81**
	PL 4 × PL 7	6.25**	JLS 60 × PL 7	34.62**
Number of seed per pod	EC 724035 × PGCP 12	2.81**	PL 4 × PL 7	28.88**
	EC 72 3909 × GC 4	2.23**	JLS 60 × PL 7	20.29*
	GC 7 × GC 4	2.09**	EC 72 3909 × GC 4	16.94*
	GC 3 × PL 7	1.45**		
Pod length	GC 7 × GC 4	1.83**	GC 3 × PL 7	18.56**
	GC 3 × PL 7	1.80**	PL 4 × PL 7	18.05**
	EC 724035 × PGCP 12	1.55**	JLS 60 × PL 7	10.66**
	JLS 60 × PL 7	1.30**	PL 4 × GC 4	6.88*
Seed yield per plant	GC 7 × GC 4	19.32**	PL 4 × PL 7	35.13**
	JLS 60 × GC 4	6.76*	EC 724035 × PGCP 12	27.05**
	EC 724035 × PGCP 12	12.14**	JLS 60 × PL 7	24.76**
			PL 4 × PGCP 12	22.49**
100-seed weight	PGCP 6 × PGCP 12	3.56**	EC 724035 × PL 7	22.66**
	EC 72 3909 × PGCP 12	2.83**	PGCP 6 × PGCP 12	21.27**
	GC 7 × GC 4	2.10**	EC 72 3909 × PGCP 12	17.87**
	GC 3 × PL 7	0.87*	EC 724035 × GC 4	10.71*

*, **, Significant at 5% and 1% levels, respectively.

pods. As a result, these crosses were recommended for more analysis in upcoming breeding programmes since they had the potential to produce good transgressive segregants for seed yield per plant and its component features. According to Debbarma *et al.* (2022); Joshi *et al.* (2022); Jahun *et al.* (2023) and Airina and Sarada (2023), these results are consistent.

When it came to heterosis, the hybrid, PL 4 × PL 7 showed the best parent heterosis for all the traits, with the exception of days to maturity, the number of primary branches per plant and the weight of 100 seeds. In terms of days to flowering, days to maturity, number of primary branches per plant. number of pods per plant and seed yield per plant, cross PL 4 × PGCP 12 shown higher better parent heterosis; in terms of days to maturity and number of pods per plant, cross, EC 724035 × PGCP showed the highest better parent heterosis. It was clear, therefore, that not every characteristic that affected yield contributed equitably to the heterosis for seed yield per plant. This could be because of a circumstance that negatively impacted the development of one component while favouring the development of the other. Thus, in order to create an efficient selection programme and achieve a good yield, the desired level of each component should be determined. Similar results were obtained by Kumar *et al.* (2017); Joshi *et al.* (2022); Airina and Sarada (2023) and Ratnakumari *et al* (2023).

Table 5: Overall general combining ability status of parents across productivity per se traits in cowpea.

Parents	Total rank	Overall status
Lines		
GC 3	35	H
GC 7	60	L
PGCP 6	41	L
JLS 60	29	H
EC 72 3909	31	H
EC 724035	37	L
PL 4	14	H
Final norm	35.28	
Testers		
PGCP 12	15	H
PL 7	12	H
GC 4	27	L
Final norm	18	

H = High overall gca status; L = Low overall gca status.

Parental overall gca status and hybrids overall sca and heterotic status

Four of the 7 lines, GC 3, JLS 60, EC 723909, PL 4 and two of the three testers, PGCP 12, PL 7, displayed high overall

Table 6: Overall sca status of crosses across productivity per se traits in cowpea.

Lines \ Testers	PGCP 12 (H)		PL 7 (H)		GC 4 (L)	
	Total score	Status	Total score	Status	Total score	Status
GC 3 (H)	123	L	107	L	81	H
GC 7 (L)	34	H	89	H	41	H
PGCP 6 (L)	133	L	148	L	107	L
JLS 60 (H)	107	L	56	H	144	L
EC 723909 (H)	162	L	84	H	76	H
EC 724035 (L)	25	H	95	H	64	H
PL 4 (H)	107	L	121	L	143	L
Final norm	97.47					

H = High overall sca status; L = Low overall sca status.
(H) = High overall gca status of parents; (L) = Low overall gca status of parents.

Table 7: Overall heterotic status of crosses across productivity per se traits in cowpea.

Lines \ Testers	PGCP 12 (H)		PL 7 (H)		GC 4 (L)	
	Total score	Status	Total score	Status	Total score	Status
GC 3 (H)	99	L	102	L	112	L
GC 7 (L)	35	H	141	L	46	H
PGCP 6 (L)	142	L	111	L	72	H
JLS 60 (H)	152	L	36	H	147	L
EC 723909 (H)	168	L	106	L	37	H
EC 724035 (L)	106	L	94	H	24	H
PL 4 (H)	107	L	85	H	103	L
Final norm	96.42					

H = High overall sca status; L = Low overall sca status.
(H) = High overall gca status of parents; (L) = Low overall gca status of parents.

Table 8: Distribution of crosses with high overall sca and heterotic status in relation to overall parental gca status across productivity per se traits in cowpea.

Parental gca status of crosses	Number of crosses		
	Under the category	With high (H) overall sca status	With high (H) heterotic status
H × H	8	2	2
H × L / L × H	10	6	3
L × L	3	2	3

HH: Both parents are high in their overall general combining ability.

HL / LH: One parent is high and other one is low in their overall general combining ability.

LL: Both parents are low in their overall general combining ability.

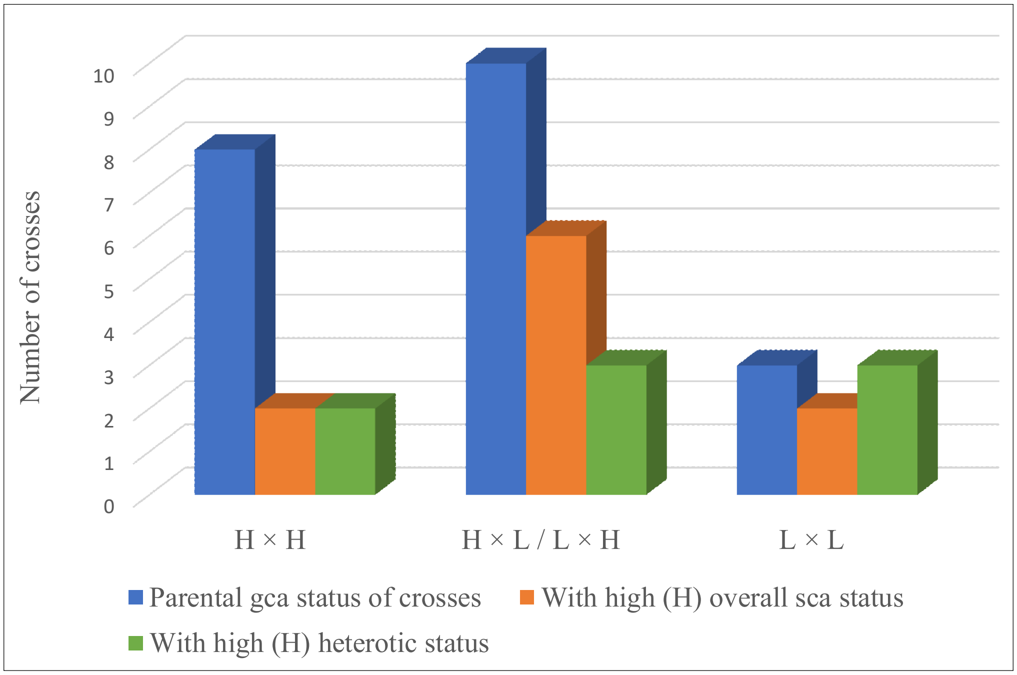

Fig 1: Frequency of heterotic hybrids in relation to gca of parents.

gca status and the remaining exhibited low overall gca status (Table 5). Similarly among hybrids, ten (47.61%) and eight (38.09%) crosses were classified as having high (H) overall sca and heterotic status, respectively and remaining were classified as having low (L) overall sca and heterotic status (Table 6 and 7). Similarly, Ramesh *et al.* (2000), Keerthi *et al.* (2016) and Parmar *et al.* (2025) classified parents based on gca, sca and heterotic status.

Relationship of overall parental gca status with hybrids overall sca and heterotic status

Distribution of crosses with high overall sca and heterotic status in relation to overall parental gca status across productivity per se traits in cowpea is presented in Table 8. No conclusive relationship could be established regarding the frequency of heterotic hybrids based on gca effects because heterotic hybrids for productivity per se traits were produced by parents with high, low, or contrasting gca effects (Fig 1). Results obtained here are in contrast to Boraiah *et al.* (2019) in Black gram where they established, requirement of parents with contrasting gca effects to realise higher frequency of hybrids with high overall sca and heterotic status.

CONCLUSION

The ability to predict parental gca impacts on hybrid heterosis, which would result in significant time and resource savings, determines how effective a breeding strategy will be. For days to flowering and days to maturity, line PL 4, PGCP 12 and tester PL 7 registered as good general combiners. Thus, these parents might be used in further earliness breeding programmes. The crosses GC 7 × GC 4, EC 724035 × PGCP 12, JLS 60 × GC 4 recorded high mean seed yield heterotic effect along with positive significant sca effect for seed yield per plant and its component characters. Hence, these crosses are recommended for more analysis in upcoming breeding programmes since they had the potential to produce good transgressive segregants for seed yield per plant and its component features. As in our study, heterotic hybrids for productivity per se traits were created by parents with high, low, or contrasting gca effects, no definite association could be established about the frequency of heterotic hybrids based on gca effects.

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Conflict of interest

Authors declare there is no conflict of interest to disclose.

REFERENCES

Airina, C.K. and Sarada, S. (2023). Heterosis for yield and resistance to mosaic disease in vegetable cowpea *Vigna unguiculata* subsp. sesquipedalis (L.) Verdcourt. *Pharma Innovation*. **12(10):** 1536-1540.

Boraiah, K.M., Byregowda, M., Keerthi, C.M., Vijayakumar, H.P., Ramesh, S. and Reena, M. (2019). Frequency of heterotic hybrids in relation to parental genetic divergence and general combining ability in blackgram *Vigna mungo* (L.) Hepper. *Legume Research-An International Journal*. **42(5):** 595-602. doi: 10.18805/LR-3916.

Clark, A. (2007). Cowpeas: *Vigna unguiculata* (L.) Walp. In: Managing Cover Crops Profitability, 3rd Edn. Sustainable Agriculture Research and Education, College Park, M.D. pp 125-129.

Debbarma, P., Kant, R., Mishra, S.B., Bharti, L.J., Rojaria, V. and Barman, M. (2022). Combining ability and heterosis studies in blackgram *Vigna mungo* (L.) hepper. *Legume Research-An International Journal*. **45(6):** 676-682. doi: 10.18805/LR-4709.

FAOSTAT, (2022). Food and Agriculture Organization of the United Nations. (http://www.fao.org/faostat/en/#data/QC.

Gandhi, M.T., Sharma, M., Patel, M.P., Soni, N.V., and Dave, G.S. (2024). Unearthing hybridization opportunities for augmenting biomass yield and harvest index in rajmash (*Phaseolus vulgaris* L.). *Journal of Food Legumes*. **37(1):** 34-39.

Gandhi, M.T., Sharma, M., Patel, M.P., Soni, N.V. and Dave, G.S. (2025). Combining ability analysis and association of yield and yield components among selected rajmash (*Phaseolus vulgaris* L.) lines. *Legume Research*. **48(10):** 1618-1626. doi: 10.18805/LR-5254.

Griffings B (1956). Concept of general and specific combining ability in relation to diallel crossing systems. *Australian Journal of Biological Sciences*. **9:** 463-493.

Jahun, B.Y., Izge, A.U., Buba, U.M. and Sabo, M.U. (2023). Combining ability study among lines of cowpea *Vigna unguiculata* L. Walp for yield and yield related components. *Journal of Agripreneurship and Sustainable Development*. **6(3):** 17-28.

Joshi, S.N., Desai, S.S., Sawardekar, S.V.,Sanap, P.B., Mane, A. V. and Kunkerkar, R.L. (2022). Heterosis for yield and yield-related traits in red cowpea *Vigna unguiculata* L. Walp. *Pharma Innovation*. **11(4):** 1125-1130.

Kamara, A.Y., Ewansiha, S.U., Ajeigbe, H.A., Okechukwu, R., Tefera, H., Boukar, O. and Omoigui, L.O. (2010). Improvements in Grain and Fodder Yield of Cowpea (*Vigna unguiculata*) Varieties Developed in The Sudan Savannas of Nigeria Over the Past Four Decades. In: Proceedings of the Fifth World Cowpea Conference, Saly, Senegal. pp. 171-188.

Kempthorne, O. (1957). An Introduction to Genetic Statistics. John Wiley and Sons, Inc., New York.

Keerthi, C.M., Ramesh, S., Byregowda, M., Mohan Rao, A., Vaijayanthi, P.V., Chandrakant, N. and Shivakumar, M.S. (2016). High yielding vs. low yielding testers to identify advanced breeding lines for general combining ability in dolichos bean (*Lablab purpureus*). *J. Crop Improv*. **30:** 95-106.

Kempthorne, O. (1957). An Introduction to Genetic Statistics. New York, John Wiley and Sons, 1st Edn.: pp 456-471.

Kumar, S., Sridhar, K., Kumar, V. and Kulkarni, N.S. (2017). Combining ability analysis in dual purpose in cowpea *Vigna unguiculata* (L.) walp. *Plant Archives*. **17(2):** 919-923.

Manivannan N. (2014). TNAUSTAT-Statistical Package.

Parmar, H.K., Sharma, M., Patel, P.R., Patel, M.P., Patel, V. and Banakar, T. (2024). Genetic variability and character association studies for yield attributes in cowpea *Vigna unguiculata* L. Walp. *International Journal of Advanced Biochemistry Research*. **8(3):** 601-605.

Parmar, H.K., Sharma, M., Patel, P.R., Soni, N.V. and Zala, H.N. (2025). Breeding cowpea (*Vigna unguiculata* L.) for high seed yield, protein content and harvest index: Genetic parameters to identify useful parents. *Legume Research*. 1-6. doi: 10.18805/LR-5381.

Patel, P.R., Sharma, M. and Patel, M.P. (2021a). Study of heritability, genetic advancement, variability and character association for yield contributing characters in pigeon pea [*Cajanus cajan* (L.) Millspaugh]. *Emergent Life Sciences Research*. **7:** 1-4.

Patel, P.R., Sharma, M., Purohit, Y., Patel, M.P. and Patel, P.J. (2021b). Stability analysis and genotype×environment interaction in medium maturing genotype of pigeonpea [*Cajanus cajan* (L.) Millsp. *Green Farming*. **12(3/4):** 95-100.

Ramesh, S., Sheriff, R.A., Rao, A.M. and Reddy, L.S.S. (2000). Prediction of the frequency of heterotic hybrids based on GCA effects of parents over a number of characters in sesame (*Sesamum indicum* L.). *Crop Res*. **19(2):** 310-314.

Ratnakumari, N., Naidu, L., Reddy, R.V.S.K., Patro, T.S.K.K., Babu, D.R. and Umakrishna, K. (2023). Studies on heterosis for pod yield and protein content in Yardlong bean *Vigna unguiculata* (L.) Walp. ssp. Sesquipedalis Verdc. *International Journal of Plant and Soil Science*. **35(19):** 1152-1159.

Sharma, M. and Sridevi, O. (2016). Genetic variability, correlation and path coefficient analysis for yield and yield related traits in chilli (*Capsicum annuum* L.). *Adv. Life Sci*. **5(1):** 144-147.

Sharma, M., Patel, M.P., Patel, P.J. and Patel, P.R. (2022). Stability analysis of yield and yield attributing traits in advanced breeding lines of cowpea *Vigna unguiculata* (L.) Walp. *Electronic Journal of Plant Breeding.* **13(3):** 901-909.

Sharma, M. and Shadakshari, Y.G. (2021). Economic heterosis in sunflower hybrids based on different cytoplasmic combinations for seed yield and its component traits. *Mysore J. Agric. Sci.* **55(2):** 35-44.

Sharma, M., Yediyur Gavisiddaiah, S., Rao, A. and Ramesh, S. (2022a). Utilization of wild species for diversifying the cytoplasmic male sterility source of sunflower (*Helianthus annuus* L.) hybrids. *Helia.* **45(76):** 71-98.

Sharma, M., Patel, P.J., Patel, P.R. and Patel, M.P. (2025). AMMI and GGE biplot analysis of multi-environmrnt seed yield data in cluster bean *Cyamopsis tetragonoloba* (L.) Taub. *Legume Research-An International Journal.* **48(4):** 597-602. doi: 10.18805/LR-4918.

Verma, A.K., Mehta, A.K., Singh, R.P., Singh, P.P. and Sharma, D. (2020). Studies on hybrid vigour for yield and contributing traits in cowpea [*Vigna unguiculata* (L.) Walp]. *Research Journal of Biotechnology.* **15(10):** 72-79.