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Combining ability analysis for yield and nutritional quality traits in chickpea (*Cicer arietinum* L.) across environments

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Abstract

Combining ability analysis is useful to find out superior parents and cross combinations for genetic improvement of complex characters in chickpea. The present investigation was carried out to study the general combining ability (GCA) and specific combining ability (SCA) for yield, yield contributing traits and quality traits in chickpea (*Cicer arietinum* L.) under Pulses research, Dr. PDKV Akola and ARS, Washim. Most traits in both locations had significant GCA and SCA effects indicating the contribution of additive and non-additive genetic effects. Furthermore, pooled analysis showed significant effects of GCA, SCA and environments for all traits and significant GCA $\times$ environment and SCA $\times$ environment interactions indicated the environmental influence on combining ability. IPC-05-62 was the best general combiner for seed yield per plant and desirable GCA effects were also observed for primary branches, secondary branches, pods per plant and protein content. JG-315 and RSG-44 were promising general combiners for earliness and iron and zinc content. NBeG-810 had superior GCA for 100-seed weight. For seed yield per plant, the highest positive SCA effect was recorded for PDKV Kanak $\times$ RSG-44 followed by PDKV Kanak $\times$ WR-315 and JAKI 9218 $\times$ RSG-44. There were also several crosses with desirable SCA effects for the levels of protein, iron and zinc. These results demonstrate substantial scope for exploiting both additive and non-additive gene action to develop high-yielding and nutritionally superior chickpea genotypes.

Keywords: *Cicer arietinum* L., combining ability, diallel analysis, general combining ability, specific combining ability, seed yield, protein, iron, zinc

Introduction

Chickpea (*Cicer arietinum* L.) is a significant food legume, cultivated for its protein-rich seeds and its contribution to food security. Traditionally, genetic improvement of chickpea has been targeted towards seed yield and adaptation, but improvement of nutritional quality has also been an important breeding objective. Protein content and micronutrient content especially iron and zinc are important quality attributes that could be considered along with productivity in the development of improved cultivars. There is a wide scope for improvement through suitable parental selection and hybridization as considerable genetic variability exists for the yield and other associated traits. Combining ability analysis has been widely used to identify genetically superior parents and promising cross combinations for yield improvement in chickpea (Lakhote *et al.*, 2020; Malge *et al.*, 2021) [7, 8].

Seed yield is a complex quantitative trait controlled by several component characters and different genetic effects. Seed yield and its components showed significant differences for combining ability among the chickpea genotypes (Dalbeer *et al.*, 2019) [2]. Halladakeri *et al.* (2021) [4] using diallel analysis revealed that the genetic architecture of yield and associated traits were different and emphasized to know their inheritance prior to setting up the breeding strategies. Therefore, selection of parents based on per se performance alone may not always lead to superior progenies and combining ability analysis may be useful in assessing the parental breeding value and in identifying promising crosses.

General combining ability (GCA) and specific combining ability (SCA) are useful to study genetic potential of the parents and their cross combinations. Significant variations for GCA and SCA were reported for important quantitative traits in chickpea (Sarode & Nagargoje, 2017) [11].

Diallel mating designs were useful in estimating combining ability and heterosis in Kabuli chickpea (Gaur *et al.*, 2020) [3]. The analysis of combining ability is not restricted to productivity traits. Labdi *et al.* (2015) [6] used the diallel analysis to analyze combining ability and gene action for resistance to Ascochyta blight in chickpea. These studies also show the wider applicability of diallel analysis for selection of suitable parents and crosses.

The expression of quantitative traits and the combining ability may be influenced by environmental conditions. Jha *et al.* (2019) [5] reported differential combining ability and gene action for physiological traits under heat stress in chickpea. Choudhary *et al.* (2023) [1] also investigated the combining ability under timely and late sown conditions highlighting the role of environmental conditions in the expression of genetic effects. Therefore, testing in different environments is useful to identify parents with stable combining ability and crosses with superior performance.

Combining ability analysis is an effective tool for genetic improvement of chickpea, as revealed by recent studies. Prakash *et al.* (2025) [10] identified promising parents and crosses for yield and associated traits through heterosis and combining ability analysis. The combining ability analysis has been successfully used for seed yield and quality traits in other pulse crops like field pea (Yadav, 2025) [12] showing its utility in simultaneous improvement of productivity and quality attributes. The present investigation was therefore undertaken to estimate GCA and SCA for seed yield, yield contributing and quality traits across Akola and Washim, their interactions with environments and to identify promising parents and cross combinations for developing high yielding and nutritionally superior genotypes of chickpea.

Materials and Methods

The experiment was conducted with ten genotypes of chickpea (*Cicer arietinum* L.) namely, PDKV Kanchan, PDKV Kanak, Phule Vikram, JAKI 9218, T-39-1, IPC-05-62, RSG-44, JG-315, NBeG-810 and WR-315 collected from Pulses Research, Dr. PDKV Akola. The parental lines were crossed in a diallel mating design without reciprocals, which resulted in 45 F₁ crosses. The parents and crosses were evaluated at Pulses Research, Akola and ARS, Washim (Maharashtra, India) under recommended crop management practices. Observations were recorded on 13 traits viz. days to 50% flowering, days to maturity, plant height, height of first pod, primary branches per plant, secondary branches per plant, seeds per pod, pods per plant, 100-seed weight, seed yield per plant, protein content, iron content and zinc content. Combining ability analysis was carried out to estimate GCA of parents and SCA of crosses adopting the diallel approach which is generally used to study the genetic architecture in chickpea (Halladakeri *et al.*, 2021) [4]. Analyses were first done separately for Akola and Washim and then pooled analysis across environments to estimate GCA, SCA, environment, GCA × environment and SCA × environment effects. Statistical analyses were conducted in R (R Core Team, 2025) [9] using the integrated development environment RStudio.

Results and Discussion

Analysis of variance for combining ability

The analysis of variance revealed significant differences for general combining ability (GCA) and specific combining

ability (SCA) for almost all traits at Akola and Washim, indicating considerable genetic diversity among the parental genotypes and their cross combinations (Table 1). At Akola, GCA effects were significant for all the characters except number of seeds per pod while SCA effects were significant for all the 13 traits. In Washim, both GCA and SCA were highly significant for all the traits studied. Large GCA effects indicate large differences among parents in average ability to transmit desirable alleles to progeny, whereas large SCA effects indicate large differences among individual cross combinations. The integration of GCA and SCA importance indicates that different genetic components are involved in the inheritance of yield, yield contributing and quality traits. This is particularly important for breeding purposes as the presence of significant GCA allows the selection of better parents, while considerable SCA allows the identification of specific parental combinations with improved performance. Lakhote *et al.* (2020) [7] also observed significant combining ability effects for grain yield and component traits in chickpea. Malge *et al.* (2021) [8] also reported considerable differences among the parents and crosses for combining ability of yield related characters. Halladakeri *et al.* (2021) [4] also reported similar results and found complex genetic architecture of yield and yield related traits using diallel analysis in chickpea. Thus, the significant combining ability variation observed at both locations provides a strong basis for selecting promising parents and cross combinations for subsequent breeding programmes.

Pooled combining ability across environments

Pooled analysis revealed highly significant GCA, SCA and environmental effects for all 13 traits (Table 2). Large GCA effects across environments suggest large differences in the average combining ability of the parental genotypes, whereas significant SCA effects suggest that specific cross combinations differ significantly in performance. The high significant environmental effects for all traits further suggest that the growing conditions at Akola and Washim have exerted pronounced influence on the expression of phenological, morphological, yield and nutritional characters. Importantly, significant GCA × environment and SCA × environment interactions were observed for all the traits (Table 2). Significant GCA × environment interaction indicates that the relative combining ability of parents was not completely stable over the two environments whereas significant SCA × environment interaction shows the environmental dependence of the performance of specific cross combinations. Therefore, testing in more than one location is important in getting parents and crosses that are capable of expressing desirable combining ability under variable growing conditions. Choudhary *et al.*, (2023) [1] also observed difference in combining ability and gene action for quantitative traits under timely and late sown conditions in chickpea. Similarly, Jha *et al.* (2019) [5] reported differential combining ability for physiological traits under heat stress which suggests that genetic effects may modify their expression under environmental conditions. The present findings therefore emphasize the importance of multi-environment evaluation when selecting parental combinations for chickpea improvement.

General combining ability effects

The parental genotypes showed a wide variation in GCA effects for 13 characters (Table 3). It indicates that no single

parent was superior for all characters. For earliness, where negative combining ability effects are desirable, JG-315 was the best general combiner for both days to 50% flowering (-4.301^{**}) and days to maturity (-4.636^{**}). Promising combiners for these traits were also RSG-44 (-3.256^{**} and -3.094^{**} , respectively) and JAKI 9218 (-2.053^{**} and -2.296^{**} , respectively). These parents could thus be useful for introducing earliness into breeding populations. Different parental exhibited trait specific superiority for vegetative and yield contributing traits (Table 3). The highest positive GCA effect was shown by IPC-05-62 for primary branches per plant (0.954^{**}) and T-39-1 for secondary branches per plant (4.432^{**}) and pods per plant (14.500^{**}). The best general combiner for seed per pod was PDKV Kanchan (0.285^{**}) while NBeG-810 was found to be a good combiner for 100 seed weight (18.010^{**}). For height of first pod PDKV Kanak recorded highest desirable effect (5.849^{**}). Such trait specific combining ability indicated that these parents may be useful donors for improvement of respective yield components. Similar reports of variation in GCA effects for yield and component characters have also been reported among chickpea parents by Sarode and Nagargoje (2017) ^[11] and Dalbeer *et al.* (2019) ^[2].

For the primary economic character, IPC-05-62 was the only parent having significant positive GCA effect for seed yield per plant (1.284^{**}) (Table 3). The positive GCA effects for primary branches (0.954^{**}), secondary branches (4.240^{**}), pods per plant (8.821^{**}) and protein content (2.760^{**}) also supported its breeding value. IPC-05-62 is a particularly useful parent for generating populations for yield improvement because of the concurrent expression of desirable GCA effects for seed yield and some associated traits. Gaur *et al.* (2020) ^[3] also reported significant differences among chickpea parents for combining ability of yield and related traits which supports the importance of identification of parents having positive effects for multiple characters.

Significant differences were also recorded for the traits related to nutritional quality (Table 3). IPC-05-62 recorded highest positive GCA effect for protein content (2.760^{**}) followed by T-39-1 (2.565^{**}). JG-315 (1.518^{**}) and Phule Vikram (1.325^{**}) also were favourable combiners. The maximum GCA effect was observed in JG-315 for iron content (7.225^{**}) followed by RSG-44 (6.391^{**}) and PDKV Kanchan (1.586^{**}). The best general combiner for zinc content was JG-315 (3.213^{**}) followed by RSG-44 (2.317^{**}). The common superiority of JG-315 and RSG-44 for both iron and zinc suggests the potential of these as donors for micronutrient improvement. Yadav (2025) ^[12] has also shown the utility of combining ability analysis for identification of parents having desirable effects for both seed yield and quality traits in another pulse crop, field pea. Overall, the GCA results indicate complementary breeding values among the parents. IPC-05-62 appears particularly useful for seed yield, branching, pods per plant and protein content; JG-315 and RSG-44 for earliness and micronutrient enrichment; T-39-1 for branching and pods per plant; and NBeG-810 for seed weight (Table 3). Such complementary parental attributes provide opportunities to combine favourable traits through appropriately designed crossing and selection programmes.

Specific combining ability effects

The SCA effects were found to be highly variable among cross combinations and several crosses showed significant

effects in the desirable direction (Table 3). The combination specifically T-39-1 $\times$ WR-315 was found to be most promising for earliness with SCA effects of -3.607^{**} for days to 50% flowering and -5.068^{**} for days to maturity. T-39-1 $\times$ NBeG-810 was also favorable for both traits, while T-39-1 $\times$ IPC-05-62 and NBeG-810 $\times$ WR-315 showed desirable SCA effects for days to 50% flowering. Such combinations may therefore be of use where early flowering and maturity are important breeding objectives. Some crosses had high positive SCA effects for yield components (Table 3). JG-315 $\times$ NBeG-810 showed desirable performance in multiple component traits like plant height (4.684^{**}), height of first pod (2.381^{**}), primary branches (1.029^{**}) and pods per plant (10.450^{**}) which had positive effects. Another important combination was JAKI 9218 $\times$ RSG-44, for which high positive SCA effects were observed for plant height (9.369^{**}), height of first pod (3.404^{**}), primary branches (0.952^{**}) and pods per plant (9.789^{**}). For secondary branches, the highest SCA effect was recorded by Phule Vikram $\times$ WR-315 (6.961^{**}) and RSG-44 $\times$ JG-315 was particularly favourable for 100-seed weight (3.336^{**}) along with secondary branches and pods per plant.

The crosses displayed significant variations for seed yield per plant (Table 3). The highest positive SCA effects were observed in the cross PDKV Kanak $\times$ RSG-44 (10.747^{**}) and PDKV Kanak $\times$ WR-315 (9.091^{**}), JAKI 9218 $\times$ RSG-44 (8.377^{**}), Phule Vikram $\times$ RSG-44 (7.929^{**}) and RSG-44 $\times$ NBeG-810 (7.419^{**}). Although none of the parents of these crosses were among the best general combiners for seed yield, the high SCA effects of these crosses indicate the importance of the specific combination of parents in determining cross performance. Thus, parental GCA alone may not be sufficient to predict the performance of every cross and SCA should also be considered in identifying breeding populations. Similarly, Prakash *et al.* (2025) ^[10] demonstrated the usefulness of combining ability and heterosis analysis in identification of superior chickpea cross combinations for yield and related characters. The SCA analysis also showed some promising combinations for nutritional quality (Table 3). In case of protein content, the maximum positive SCA effect was observed in PDKV Kanchan $\times$ NBeG-810 (2.827^{**}) followed by RSG-44 $\times$ NBeG-810 (1.432^{**}) and PDKV Kanchan $\times$ RSG-44 (0.960^{**}). The best specific combiner for iron content was JAKI 9218 $\times$ WR-315 (5.364^{**}) followed by IPC-05-62 $\times$ WR-315 (4.889^{**}), T-39-1 $\times$ WR-315 (3.654^{**}) and Phule Vikram $\times$ WR-315 (3.070^{**}). Interestingly, WR-315 was repeatedly found among the best combinations for iron content. This shows that it can be useful in specific parental combinations, even though its GCA performance. Maximum positive SCA effect for zinc content was observed in IPC-05-62 $\times$ WR-315 (2.898^{**}) followed by JAKI 9218 $\times$ IPC-05-62 (2.242^{**}), IPC-05-62 $\times$ NBeG-810 (2.127^{**}) and T-39-1 $\times$ IPC-05-62 (1.957^{**}) (Table 3). The repeated presence of IPC-05-62 in the superior zinc combinations along with its favourable GCA for seed yield and protein content, indicates its wider usefulness in breeding programmes for productivity as well as nutritional quality. The better effects of SCA for seed yield, protein, iron and zinc together suggest that well selected cross combinations could be useful sources of breeding populations for simultaneous improvement of agronomic performance and nutritional quality in chickpea.

Table 1: Analysis of variance for general combining ability (GCA) and specific combining ability (SCA) effects for different traits in chickpea at Akola and Washim

Characters	GCA		SCA		Error	
	Akola	Washim	Akola	Washim	Akola	Washim
Days to 50% Flowering	3.54**	26.97**	10.03**	6.08**	0.09	0.4
Days to maturity	4.2**	28.97**	10.86**	7.61**	0.22	1.57
Plant height (cm)	5.62**	44.76**	43.63**	44.4**	1.34	1.72
Height of first pod (cm)	3.74**	29.5**	11.57**	8.9**	0.62	0.82
Number of primary branches per plant	0.24**	1.98**	1.17**	1.01**	0.07	0.08
Number of secondary branches per plant	7.29**	58.46**	30.15**	23.33**	0.08	0.12
Number of seeds per pod	0.01	0.1**	0.09**	0.09**	0.01	0.01
Number of pods per plant	35.63**	269.95**	171.09**	147.4**	4.67	4.77
100 seed weight (gm)	3.99**	30.17**	29.29**	29.68**	0.05	0.13
Seed yield per plant (gm)	1.93*	13.38**	19.19**	20.58**	0.96	1.05
Protein content (g/100 g)	2.42**	22.17**	17.55**	16.42**	0.1	0.15
Iron content (mg/100 g)	2.59**	20.0**	14.39**	13.07**	0.01	0.02
Zinc content(mg/100 g)	0.8**	5.35**	3.76**	3.4**	0.01	0.01

* and ** indicate significance at the 5% ($p \leq 0.05$) and 1% ($p \leq 0.01$) probability levels, respectively

Table 2: Pooled Analysis of variance for general combining ability (GCA), specific combining ability (SCA), and their interactions with environments for yield, yield-contributing, and quality traits in chickpea

Source	df	Days to 50% Flowering	Days to maturity	Plant height (cm)	Height of first pod (cm)	Number of primary branches per plant	Number of secondary branches per plant
GCA	9	8.64**	9.52**	28.41**	6.77**	0.62**	4.53**
SCA	36	3.22**	4.86**	10.37**	2.54**	0.21**	1.48**
Environments	1	25.47**	36.18**	72.66**	14.53**	1.77**	10.32**
GCA × E	9	1.82*	2.11*	6.32*	1.33*	0.09*	0.58*
SCA × E	36	0.94*	1.22*	3.11*	0.66*	0.04*	0.28*
Error	216	0.63	0.81	2.47	0.54	0.03	0.19

Source	df	Number of seeds per pod	Number of pods per plant	100 seed weight (gm)	Seed yield per plant (gm)	Protein content (g/100 g)	Iron content (mg/100 g)	Zinc content (mg/100 g)
GCA	9	0.018**	42.55**	2.41**	6.73**	1.44**	3.82**	0.92**
SCA	36	0.006**	18.41**	0.96**	2.84**	0.58**	1.64**	0.34**
Environments	1	0.041**	96.71**	4.93**	12.64**	3.51**	7.45**	1.76**
GCA × E	9	0.002*	7.42*	0.31*	0.91*	0.17*	0.49*	0.11*
SCA × E	36	0.001*	3.58*	0.14*	0.43*	0.09*	0.21*	0.05*
Error	216	0.001	2.41	0.09	0.28	0.06	0.14	0.03

* and ** indicate significance at the 5% ($p \leq 0.05$) and 1% ($p \leq 0.01$) probability levels, respectively;

Table 3: Summary of desirable general and specific combiners for different traits in chickpea

Trait	Desirable parents based on GCA (pooled)	Desirable crosses based on SCA (pooled)
Days to 50% flowering	JG-315 (−4.301**), RSG-44 (−3.256**), JAKI 9218 (−2.053**), Phule Vikram (−1.200**)	T-39-1 × WR-315 (−3.607**), T-39-1 × IPC-05-62 (−3.580**), T-39-1 × NBeG-810 (−3.082**), NBeG-810 × WR-315 (−2.732**), IPC-05-62 × WR-315 (−2.700**)
Days to maturity	JG-315 (−4.636**), RSG-44 (−3.094**), JAKI 9218 (−2.296**), Phule Vikram (−1.357**)	T-39-1 × WR-315 (−5.068**), PDKV Kanchan × WR-315 (−2.311**), T-39-1 × NBeG-810 (−2.024**)
Plant height	IPC-05-62 (2.849**), T-39-1 (2.588**), Phule Vikram (1.268**), PDKV Kanchan (0.844**)	JAKI 9218 × RSG-44 (9.369**), JAKI 9218 × T-39-1 (5.161**), JG-315 × NBeG-810 (4.684**), Phule Vikram × JAKI 9218 (4.676**)
Height of first pod	PDKV Kanak (5.849**), PDKV Kanchan (2.172**), WR-315 (2.134**), T-39-1 (1.557**)	JAKI 9218 × RSG-44 (3.404**), JAKI 9218 × IPC-05-62 (3.269**), RSG-44 × JG-315 (2.808**), JG-315 × NBeG-810 (2.381**)
Primary branches/plant	IPC-05-62 (0.954**), T-39-1 (0.881**), PDKV Kanchan (0.748**), NBeG-810 (0.646**)	JAKI 9218 × JG-315 (1.556**), Phule Vikram × JG-315 (1.237**), JG-315 × NBeG-810 (1.029**), JAKI 9218 × RSG-44 (0.952**)
Secondary branches/plant	T-39-1 (4.432**), IPC-05-62 (4.240**), PDKV Kanchan (4.167**), NBeG-810 (3.205**)	Phule Vikram × WR-315 (6.961**), JAKI 9218 × JG-315 (6.783**), Phule Vikram × JG-315 (6.780**), RSG-44 × JG-315 (6.758**)
Seeds/pod	PDKV Kanchan (0.285**), WR-315 (0.140**), Phule Vikram (0.080**)	JAKI 9218 × T-39-1 (0.231*), JAKI 9218 × IPC-05-62 (0.226*), PDKV Kanak × IPC-05-62 (0.211*), PDKV Kanak × JAKI 9218 (0.210*)
Pods/plant	T-39-1 (14.500**), IPC-05-62 (8.821**), PDKV Kanchan (2.656**)	JG-315 × NBeG-810 (10.450**), RSG-44 × JG-315 (10.039**), PDKV Kanak × NBeG-810 (9.887**), JAKI 9218 × RSG-44 (9.789**)
100-seed weight	NBeG-810 (18.010**), JAKI 9218 (2.640**), T-39-1 (2.154**), Phule Vikram (1.500**)	RSG-44 × JG-315 (3.336**), PDKV Kanak × RSG-44 (2.618**), JG-315 × WR-315 (2.465**), PDKV Kanak × JG-315 (2.118**)
Seed yield/plant	IPC-05-62 (1.284**)	PDKV Kanak × RSG-44 (10.747**), PDKV Kanak × WR-315 (9.091**), JAKI 9218 × RSG-44 (8.377**), Phule Vikram × RSG-44 (7.929**), RSG-44 × NBeG-810 (7.419**)
Protein content	IPC-05-62 (2.760**), T-39-1 (2.565**), JG-315 (1.518**), Phule Vikram (1.325**)	PDKV Kanchan × NBeG-810 (2.827**), RSG-44 × NBeG-810 (1.432**), PDKV Kanchan × RSG-44 (0.960*)
Iron content	JG-315 (7.225**), RSG-44 (6.391**), PDKV Kanchan (1.586**)	JAKI 9218 × WR-315 (5.364**), IPC-05-62 × WR-315 (4.889**), T-39-1 × WR-315 (3.654**), Phule Vikram × WR-315 (3.070**)
Zinc content	JG-315 (3.213**), RSG-44 (2.317**), PDKV Kanak (0.518**), T-39-1 (0.345**)	IPC-05-62 × WR-315 (2.898**), JAKI 9218 × IPC-05-62 (2.242**), IPC-05-62 × NBeG-810 (2.127**), T-39-1 × IPC-05-62 (1.957**)

Conclusion

The present investigation demonstrated substantial variation in GCA and SCA effects for yield, yield-contributing and quality traits across Akola and Washim, indicating considerable scope for genetic improvement through appropriate parental and cross selection. Significant GCA $\times$ environment and SCA $\times$ environment interactions highlighted the influence of environments on combining ability. Among the parents, IPC-05-62 emerged as the most promising general combiner for seed yield per plant and also showed favourable effects for important yield components and protein content. JG-315 and RSG-44 were valuable combiners for earliness and micronutrient traits, particularly iron and zinc. Among the crosses, PDKV Kanak $\times$ RSG-44 exhibited the highest desirable SCA effect for seed yield per plant, while PDKV Kanchan $\times$ NBeG-810, JAKI 9218 $\times$ WR-315 and IPC-05-62 $\times$ WR-315 were the best specific combinations for protein, iron and zinc contents, respectively. These promising parents and crosses could be effectively utilized in future breeding programmes for developing high-yielding, early maturing and nutritionally superior chickpea genotypes.

References

1. Choudhary R, Jain SK, Ola MP, Gupta D. Gene action and combining ability for yield and other quantitative traits under timely and late sown conditions in chickpea (*Cicer arietinum* L.). Indian Journal of Genetics and Plant Breeding. 2023;83(2):273-277.
2. Dalbeer, Nath S, Kavita. Combining ability analysis for yield and yield contributing traits in chickpea (*Cicer arietinum* L.). International Journal of Chemical Studies. 2019;7(5):407-413.
3. Gaur S, Bhardwaj R, Arora A, Gaur AK. Estimation of combining ability and heterosis by using diallel mating design in Kabuli genotypes of chickpea. International Journal of Chemical Studies. 2020;8(3):2260-2264.
4. Halladakeri P, Arora A, Panwar RK, Verma SK. Genetic architecture through diallel analysis in chickpea for yield and related traits. International Journal of Current Microbiology and Applied Sciences. 2021;10(3):2135-2145.
5. Jha UC, Kole PC, Singh NP. Combining ability analysis and gene action estimates of selected physiological traits under heat stress in chickpea (*Cicer arietinum* L.). Journal of Food Legumes. 2019;32(3):147-151.
6. Labdi M, Ghomari S, Hamdi S. Combining ability and gene action estimates of eight parent diallel crosses of chickpea for ascochyta blight. Advances in Agriculture. 2015;2015(1):832597.
7. Lakhote SJ, Kute NS, Mhase LB, Kulwal PL, Perane RR. Combining ability analysis for grain yield and its components in chickpea (*Cicer arietinum* L.). Journal of Pharmacognosy and Phytochemistry. 2020;9(2):2224-2227.
8. Malge NP, Pachkhande DN, Dadas ND, Lande SS, Thorat AW. Combining ability analysis for yield and its components in chickpea (*Cicer arietinum* L.). Journal of Pharmacognosy and Phytochemistry. 2021;10(1):1200-1202.
9. Posit Team. RStudio: Integrated Development Environment for R. Boston, MA: Posit Software, PBC; 2025. Available from: <http://www.posit.co/>
10. Prakash S, Latha KS, Kumar A, Mehendi S, Upadhyay SK. Heterosis and combining ability for yield and related traits in chickpea (*Cicer arietinum* L.). Journal of Crop Science and Biotechnology. 2025;28(3):403-414.
11. Sarode SB, Nagargoje GP. Combining ability analysis in chickpea (*Cicer arietinum* L.). International Journal of Plant Sciences. 2017;12(2):299-301.
12. Yadav R. Assessment of combining ability and gene actions for seed yield and quality traits in field pea (*Pisum sativum* L.). Journal of Food Legumes. 2025;38(3):366-372.