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Research Article

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# Heterosis and Combining Ability Study for Yield Contributing Traits in Chickpea (*Cicer arietinum* L.)

**Bukke Naveen Kumar Naik and Suhel Mehandi***

*Department of Genetics and Plant Breeding, School of Agriculture, Lovely Professional University, Punjab, India*

***Correspondence to:**
Suhel Mehandi
Department of Genetics and Plant Breeding,
School of Agriculture,
Lovely Professional University,
Punjab, India.
**E-mail:** suhel.26963@lpu.co.in

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## Abstract

Chickpea (*Cicer arietinum* L.) is cool season leguminous crop, renowned for its high protein content, particularly in regions dependent on plant-based diets. This study investigates genetic diversity, heterosis, and combining ability in chickpea to enhance yield and key agronomic traits. Conducted during the 2023 - 2024 rabi season, the research utilized a line × tester design, involving eight lines and four testers. The analysis revealed significant genetic variability among lines and crosses for several traits, including days to flowering (DF), plant height (PHT), pods per plant (PP), and seed yield per plant (SYPP). Both general combining ability (GCA) and specific combining ability (SCA) effects were assessed, identifying promising parent lines and crosses. Several combinations demonstrated positive heterosis for yield traits, with notable examples such as PBG 7 × NBEG-3 and IPC 12-211 × Katila showcasing strong yield potential. These findings offer valuable insights into the genetic architecture of chickpea, which can be utilized to optimize breeding strategies aimed at enhancing productivity. The study emphasizes the importance of leveraging genetic diversity to develop high-yielding chickpea varieties that can contribute to food security and improve the livelihoods of farmers in chickpea-growing regions.

## Keywords

Chickpea, Heterosis, Combining ability, General combining ability, Specific combining ability, Line × tester, Hybridization

## Introduction

Chickpea is a self-pollinated crop of family Leguminosae. Chickpea is commonly known as gram, chana and Bengal gram. Chickpea plant is a diploid species with 2n = 2x = l6 chromosomes. Chickpea is said to be one of the first grain legumes domesticated by humans in the old world [1]. Pulses are nutritionally rich foods that enhance the overall value of cereal-based diets, especially for low- and middle-income populations. They are an ideal protein source for poorer communities with limited access to animal proteins. When combined with cereals, pulses provide a more balanced amino acid profile, approaching the optimal ratio for human nutrition. This makes them a key component in meeting dietary needs, particularly for those who rely on plant-based diets [2]. The protein content in chickpea genotypes ranges from 12.6 - 30.5% and both Kabuli and desi cultivars have marginal differences in protein contents. The average crude protein content in desi, Kabuli and wild species, was found to be 25.31, 24.67, and 24.30%, respectively. In 2022, India emerged as the leading producer of chickpea globally, with a total area harvested of 10.74 million hectares, yielding a production of 13.54 million tons and an average productivity of 1261 kg/ha. In comparison, the global chickpea scenario reported a total harvested area of 14.81 million hectares, with a production of 18.10 million tons and a slightly lower average yield of 1222

kg/ha. These figures clearly highlight India's dominant position, contributing approximately three-fourths of the world's chickpea output with productivity marginally higher than the global average [3]. Genetic diversity in parent plants is key to improving chickpea varieties. Using heterosis, or hybrid vigor, is a breeding approach to boost productivity. Combining ability analysis helps breeders select suitable parents and understand gene action, guiding future breeding strategies [4].

This can be of immense help to plant breeders in choosing desirable genotypes for a breeding program to provide valuable information regarding cross combinations to be exploited commercially [5]. Assessing the performance and compatibility of genotypes is crucial for optimizing hybridization success. Techniques like diallel, partial diallel, and line x tester offer different methods to estimate breeding requirements. In particular, the line x tester mating design allows for the evaluation of SCA for individual crosses and GCA for lines and testers, providing valuable insights for improving breeding strategies [6].

**Table 1:** The PG and their source.

| S no | Lines | Origin/Source |
|---|---|---|
| 1 | L1 (PBG-7) | PAU/Punjab |
| 2 | L2 (E100XM) | ICRISAT/Hyderabad |
| 3 | L3 (IPC 12-211) | ICAR-IIPR/Kanpur |
| 4 | L4 (JG 11) | JNKVV/Jabalpur |
| 5 | L5 (BGD-72) | IARI/Dharwad |
| 6 | L6 (GNG 1581) | ARS/Rajasthan |
| 7 | L7 (PBG-8) | PAU/Punjab |
| 8 | L8 (IPC 15-12) | ICAR-IIPR/Kanpur |
| **Testers** | | |
| 1 | T1 (Radhachoti) | Rajasthan |
| 2 | T2 (JAKI-9218) | PDKV/Maharashtra |
| 3 | T3 (NBEG-3) | ARS/Andhra Pradesh |
| 4 | T4 (KATILA) | Rajasthan |
| **Checks** | | |
| 1 | PBG 5 | Punjab |
| 2 | CSJ 515 | Punjab |

# Materials and Methods

## Plant material and field experiment

The study used a line x tester design with 8 chickpea lines (PBG-7, E100XM, IPC 12-211, JG 11, BGD-72, GNG 1581, PBG-8, and IPC 15-12) and 4 testers (RADHA CHOTI, JAKI-9218, NBEG-3, and KATILA desi chickpea genotypes) (Table 1). It was conducted during the 2023 - 2024 rabi season at the School of Agriculture, Lovely Professional University, Punjab, India. The seeds were planted by dibbling, with each genotype sown in 3 replicates using a randomized complete block design with spacing of 45 × 10 cm.

## Statistical analysis

The analysis of variance (ANOVA) was conducted following Hayman [7], and combining ability for the line x tester design was analyzed using Kempthorne's method [8]. Data were processed in R using the Agricolae package (Version 1.3-5) [9, 10]. Heterosis for each trait was calculated based on Hays et al. [11] and Fonseca and Patterson [12], with heterobeltiosis and standard heterosis (SH) estimated as per Kempthorne [8].

# Results and Discussion

## ANOVA

The ANOVA reveals significant genetic variability among crosses, lines, and line × tester interactions for several traits, including DF, PHT, PP, and SYPP. Significant replicate effects in traits like PHT and SYPP suggests environmental influences. The line effects are pronounced, indicating that selecting specific (Table 2).

The significant line × tester interactions imply SCA, indicating that the performance of hybrids is influenced by the unique combinations of lines and testers. This genetic diversity is crucial for developing superior hybrids in breeding programs [13-14].

ANOVA for combining ability revealed significant differences among the crosses for several traits, indicating the presence of genetic variability. Specifically, the crosses showed highly significant differences for traits like days of 50% flowering (DFF), days to maturity (DTM), PHT, PP, biological yield per plant (BYPP), harvest index (HI), and SYPP. The line effects were significant for DFF, days of first podding (DFP) and SYPP, suggesting that some lines contributed more significantly to the variation in these traits. Line × tester interactions were also significant for many traits, including PHT, PP and HI, indicating that the performance of crosses is influenced by the specific combination of lines and testers. These findings highlight the importance of both additive and non-additive genetic variances in the expression of these traits, providing valuable insights into selecting parent lines in breeding programs [15].

## Combining ability effects

### GCA effects

GCA effects indicate significant variations among the parental lines across various traits. L3 exhibited highly significant positive effects for traits such as DFF (6.708**), Primary branches per plant (PBP) (0.928**), PP (5.790**), and seed germination (SG) (5.425**), suggesting its potential as a strong general combiner for early flowering, higher branching, and pod production (Table 3). L4 showed significant negative GCA effects for several traits, including PHT (-3.092*) and SYPP (-5.199**), indicating it may not be suitable for improving these characteristics. Conversely, L8 demonstrated positive effects on PHT (3.442*) and SYPP (3.205**), making it a good candidate for enhancing these traits. Significant negative GCA effects in L6 for DFF (-5.125**) and DFP (-4.365*) suggest it might be suitable for developing early maturing varieties. Overall, these GCA estimates help identify parent lines with desirable traits for use in breeding programs [5].

The analysis of GCA effects for the testers provided further insights. Tester Radhachoti exhibited a negative GCA effect for PHT (-2.396*) at BYPP (-3.699**) and SYPP (-1.339**), indicating it may not contribute positively to PHT and yield traits, potentially limiting its usefulness in breeding

**Table 2:** ANOVA for few characters in hybrids and parents of chickpea.

| ANOVA | DF | DFF | DFP | DTM | PHT | PBP | SBP | PP | SI | BYPP | HI (%) | SG (%) | PG (%) | SP (%) | SYPP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Replicates | 2 | 67.88* | 97.63 | 1.125 | 134.46** | 2.20* | 32.37** | 507.60** | 3.81 | 573.13** | 100.27* | 2.47 | 129.83** | 0.32 | 16.78** |
| Crosses | 31 | 97.69** | 48.81 | 59.88** | 197.76** | 2.84** | 13.18** | 273.89** | 29.82** | 91.64** | 224.88** | 9.35** | 89.53** | 15.32** | 36.10** |
| Line effect | 7 | 200.42* | 111.64* | 116.70* | 83.31 | 5.11 | 18.85 | 182.92 | 15.68 | 118.55 | 345.05 | 9.03 | 162.14 | 12.69 | 78.76* |
| Tester effect | 3 | 39.83 | 27.76 | 39.68 | 257.07 | 0.42 | 6.20 | 333.42 | 57.45 | 84.41 | 275.39 | 6.66 | 7.91 | 21.01 | 28.57 |
| Line × tester effect | 21 | 71.71** | 30.87 | 43.82 | 227.44** | 2.43** | 12.28** | 295.71** | 30.59** | 83.71* | 177.60** | 9.84** | 76.98** | 15.38** | 22.96** |
| Error | 62 | 19.25 | 36.65 | 28.59 | 26.52 | 0.53 | 1.77 | 53.20 | 3.28 | 40.45 | 28.01 | 4.04 | 11.41 | 2.08 | 3.13 |
| Total | 95 | 45.87 | 41.90 | 38.22 | 84.67 | 1.32 | 6.14 | 134.78 | 11.95 | 68.37 | 93.77 | 5.74 | 39.4 | 6.36 | 14.18 |

**Note:** SP is seed protein, PG is parental genotypes, and *, ** indicate significance at the 0.05 and 0.01 probability levels, respective.

**Table 3:** Estimates of GCA effects of parents (lines and testers).

| Parents | DFF | DFP | DTM | PHT | PBP | SBP | PP | SI | BYP | HI | SG | PG | SP | SYPP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L1 (PBG-7) | 3.12* | 2.13 | 2.06 | -3.20* | 0.53* | -0.90* | 1.64 | 0.60 | 1.62 | -2.73 | 0.44 | 3.11** | 0.17 | -1.00 |
| L2 (E100XM) | 0.54 | 2.05 | 4.64** | -1.91 | 0.03 | -0.42 | 1.44 | 0 | -3.37 | 1.54 | 0.07 | -1.18 | 0.93* | -0.43 |
| L3 (IPC 12-211) | 6.70** | 3.80* | 3.229* | 2.22 | 0.92** | 1.04** | 5.79** | 1.97*** | -2.13 | 0.54 | 0.66 | 5.42** | 0.72 | -0.76 |
| L4 (JG 11) | 3.20* | 2.30 | -0.35 | -3.09* | -0.03 | -0.97* | -6.08** | -1.45** | 2.75 | -10.81** | -0.32 | -7.03** | -1.77** | -5.19** |
| L5 (BGD-72) | -3.79 | -3.94* | -0.93 | 2.85 | 0.13 | 1.18** | 2.39 | -0.75 | 3.89* | -0.13 | 0.43 | -1.39 | -0.04 | 1.64** |
| L6 (GNG 1581) | -5.12** | -4.36* | -2.68 | -0.38 | -0.08 | -0.98* | -2.24 | -1.06* | 2.97 | 1.20 | -1.57** | 1.05 | -1.26** | 1.94** |
| L7 (PBG-8) | -2.20 | -0.94 | -4.68** | 0.08 | -1.33** | -1.04** | -3.01 | -0.29 | -1.77 | 2.15 | -0.82 | 0.88 | 0.14 | 0.60 |
| L8 (IPC 15-12) | -2.45 | -1.03 | -1.27 | 3.44* | -0.18 | 2.11** | 3.36 | 0.98 | -3.99* | 8.24** | 1.09 | -0.87 | 1.09* | 3.20** |
| T1 (Radhachoti) | -1.12 | -0.86 | -0.97 | -2.39* | 0.04 | -0.58* | -3.89** | -2.00** | 1.70 | -3.69** | 0.13 | -0.53 | -1.01** | -1.33** |
| T2 (JAKI-9218) | 1.45 | 1.46 | 1.72 | -2.82** | 0.14 | -0.26 | -2.46 | -0.43 | 1.45 | -1.99* | -0.32 | 0.67 | -0.18 | -0.42 |
| T3 (NBEG-3) | 0.70 | 0.13 | -0.97 | 4.16** | -0.09 | 0.38 | 3.49** | 1.31** | -2.10 | 3.36** | 0.68 | 0.27 | 1.24** | 1.04** |
| T4 (KATILA) | -1.04 | -0.74 | 0.22 | 1.05 | -0.17 | 0.46 | 2.86* | 1.12** | -1.04 | 2.33* | -0.49 | -0.41 | -0.04 | 0.71* |

programs aimed at enhancing these characteristics. Tester JAKI-9218 showed a positive GCA effect for DFF (1.458) at, but its impact on SYPP was negative (-0.42), suggesting it may be more suited for improving earliness rather than yield. Tester NBEG-3 had highly significant positive GCA effects for PHT (4.163**) and secondary branches per plant (SBP, 3.494**) as well as seed index (SI) (1.317**) and SYPP (1.048**) marking it as a strong tester for improving both plant architecture and yield. Tester Katila showed positive effects on SBP at 2.865* and PHT (1.054) although it had slightly negative effects on SI (-0.045) at and BYPP (1.049) indicating its potential utility for improving branching traits [16].

## SCA effects

The results of SCA analysis highlight a wide range of significant effects across various crosses for key agronomic traits (Table 4). For instance, cross PBG 7 x KATILA demonstrated substantial positive SCA effects for panicle production (14.966**), biomass yield (10.515**) and HI (3.132**), indicating strong potential for increased productivity. Similarly, E100XM × NBEG 3 showed significant positive effects for PHT (1.093*), PP (11.656**) and BYPP (9.645**), suggesting its suitability for improving yield-related traits [17].

Crosses exhibited significant negative SCA effects, which result in undesirable outcomes for certain traits. PBG 7 × NBEG 3 showed negative effects for DTM (6.464) and HI (2.447*), indicating late maturity and reduced yield potential. Similarly, IPC 12-211 × Radhachoti had negative SCA effects for BYPP (-10.078**) and SYPP (-5.549**) suggesting reduced biomass and seed yield production. These crosses may not be ideal for improving yield but could be useful in specific contexts where slower growth or longer maturity is needed.

The results reveal that several crosses performed well across multiple traits, including JG 11 × Radhachoti and IPC 15-12 × JAKI 9218, which had positive SCA effects for key traits like panicle production, biomass yield, and specific yield production. On the other hand, crosses with negative SCA effects for critical traits, such as IPC 15-12 × NBEG 3 (negative effects on DTM = -11.869 and HI = -5.358**) should be reconsidered depending on the breeding objectives [12, 14].

## Heterosis

The analysis of SYPP across various crosses demonstrated significant variability, with several combinations showing notable positive effects (Figure 1). The cross PBG 7 × NBEG-3 recorded a highly significant SYPP value of 10.88 with 33.66% superiority in heterosis over the standard check (SH). Similarly, the combination PBG 7 × Katila had a SYPP value of 12.29 and 31.19% superiority in SH, highlighting its po-

**Table 4:** Estimates of SCA effects of crosses.

| Crosses | DFF | DFP | DTM | PHT | PBP | SBP | PP | SI | BYP | HI | SG | PG | SP | SYPP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PBG 7 × Radhachoti | 1.87 | 3.19 | -4.35 | -0.8 | -0.49 | -1.51 | -5.71 | -1.46 | 7.21 | -3.31 | -0.9 | -1.53 | -0.24 | 0.1 |
| PBG 7 × JAKI-9218 | -9.37** | -5.8 | -2.39 | -3.94 | 0.5 | -1 | -2.78 | 0.27 | 0.62 | 0.53 | 0.22 | 1.25 | 0.234 | 0.86 |
| PBG 7 × NBEG-3 | 3.7 | -0.13 | 6.31* | 4.03 | -0.74 | -1.35 | -6.46 | -1.28 | 1.69 | -7.73* | -2.44* | -3.67 | -1.45 | -3.19** |
| PBG 7 × KATILA | 3.79 | 2.74 | 0.43 | 0.71 | 0.72 | 3.86** | 14.96** | 2.47* | -9.53* | 10.51** | 3.13** | 3.95* | 1.46 | 2.22* |
| E100XM × Radhachoti | -7.20** | -2.71 | 0.06 | 2.37 | -0.19 | -0.85 | -6.48 | 1.34 | 2.26 | -4.96 | -1.53 | 1.1 | 0.42 | -1.49 |
| E100XM × JAKI-9218 | -0.12 | -1.05 | 2.02 | -2.1 | -0.72 | -0.4 | -0.48 | -2.05 | 0.67 | -3.18 | -1.73 | -6.44** | 0.74 | -1.46 |
| E100XM × NBEG-3 | 0.95 | -1.05 | -0.6 | 1.04 | 1.09* | 0.4 | 11.65** | 2.82** | -3.85 | 9.64** | 2.49* | 4.35* | 2.17* | 3.21** |
| E100XM × KATILA | 6.37* | 4.82 | -1.47 | -1.31 | -0.17 | 0.85 | -4.68 | -2.11* | 0.91 | -1.49 | 0.77 | 0.98 | -2.49** | -0.25 |
| IPC 12-211 × Radhachoti | -3.04 | -1.13 | -5.18 | 0.99 | -0.48 | -1.4 | -9.73* | -5.03** | -2.42 | -10.07** | 0.21 | -0.17 | -2.98** | -5.54** |
| IPC 12-211 × JAKI-9218 | 1.04 | -0.46 | 0.43 | 0.22 | -0.44 | -1.98* | -11.33** | 1.2 | 10.88** | -10.92** | -1.99 | 2.38 | -0.28 | -2.64* |
| IPC 12-211 × NBEG-3 | -5.20* | -2.46 | 4.47 | -5.09 | -0.19 | 2.20** | 10.90* | 2.55* | -1.81 | 9.27** | 1.43 | 0.51 | 0.52 | 4.57** |
| IPC 12-211 × KATILA | 7.20** | 4.07 | 0.27 | 3.87 | 1.13** | 1.18 | 10.16* | 1.27 | -6.64 | 11.73** | 0.34 | 2.04 | 2.74** | 3.61** |
| JG 11 × Radhachoti | -0.2 | -1.63 | 5.06 | 5.71 | 0.47 | -0.47 | -2.79 | 2.66* | 2.28 | 0.34 | 0.19 | 7.61** | 2.02* | 0.72 |
| JG 11 × JAKI-9218 | 7.87** | 4.36 | 2.68 | -0.72 | -0.62 | 0.24 | 3.96 | 0.63 | -5.87 | 8.88** | 0.65 | 0.74 | -2.53** | 2.55* |
| JG 11 × NBEG-3 | -4.04 | -0.96 | -2.27 | 10.45** | -0.07 | 0.05 | -1.98 | -1.65 | 5.95 | -6.37* | -1.01 | -1.52 | -1.99* | -1.47 |
| JG 11 × KATILA | -3.62 | -1.76 | -5.47 | -15.43** | 0.15 | 0.17 | 0.81 | -1.65 | -2.36 | -2.85 | 0.16 | -6.83** | 2.51** | -1.8 |
| BGD-72 × Radhachoti | 4.45 | 2.28 | 1.31 | -10.99** | -0.59 | -0.24 | 2.29 | -0.5 | -2.18 | 1.29 | 1.77 | -10.35** | -2.49** | -0.12 |
| BGD-72 × JAKI-9218 | 0.54 | 2.61 | -3.72 | 5.79 | 0.09 | 0.27 | -0.87 | 0.09 | 0.26 | -2.26 | -0.43 | 2.76 | -0.77 | -1.11 |
| BGD-72 × NBEG-3 | 0.29 | -0.71 | 2.31 | 2.51 | 0.89* | 2.29** | 10.20* | 4.24** | -4.97 | 7.63* | 1.57 | 6.73** | 2.57** | 2.37* |
| BGD-72 × KATILA | -5.29* | -4.17 | 0.1 | 2.68 | -0.3 | -2.32** | -11.63** | -3.82** | 6.89 | -6.67* | -2.91* | 0.85 | 0.68 | -1.13 |
| GNG 1581 × Radhachoti | 2.12 | 0.36 | 0.72 | 4.97 | -0.47 | 1.06 | 2.39 | -0.65 | -2.53 | 1.73 | 1.77 | -4.13* | 1.27 | 0.21 |
| GNG 1581 × JAKI-9218 | -0.79 | -1.3 | -1.64 | -12.03** | -0.03 | -0.11 | 3.12 | -2.35* | -2.08 | 3.78 | 0.9 | -1.34 | -1.22 | 1.53 |
| GNG 1581 × NBEG-3 | 1.62 | 1.69 | -5.6 | 6.31* | 0.15 | -1.26 | -8.62* | -0.14 | 2.7 | -3.34 | -1.09 | 2.05 | -0.48 | -0.55 |
| GNG 1581 × KATILA | -2.95 | -0.76 | 6.52* | 0.75 | 0.35 | 0.31 | 3.1 | 3.15** | 1.91 | -2.17 | -1.58 | 3.41 | 0.43 | -1.19 |
| PBG-8 × Radhachoti | 3.54 | 2.28 | 2.39 | -13.22*** | -0.12 | -0.54 | 1.8 | -1.46 | -3.01 | 8.05* | -1.97 | 0.36 | 1.29 | 2.93** |
| PBG-8 × JAKI-9218 | -1.37 | -1.71 | 1.35 | 6.59* | 0.17 | 1.24 | 0.8 | 0.27 | -2 | 0.12 | 2.15 | 2.15 | 0.21 | -0.35 |
| PBG-8 × NBEG-3 | 1.7 | 1.28 | -2.6 | -4.45 | 0.22 | 0.19 | -3.81 | 0.91 | 1.59 | -5.75 | -0.84 | -3.1 | 0.74 | -2.48* |
| PBG-8 × KATILA | -3.87 | -1.84 | -1.14 | 11.08** | -0.27 | -0.89 | 1.21 | 0.27 | 3.43 | -2.42 | 0.66 | 0.58 | -2.25** | -0.09 |
| IPC 15-12 × Radhachoti | -1.54 | -2.63 | -0.02 | 10.97** | 1.89** | 3.96** | 18.22** | 5.12** | -1.6 | 6.92* | 0.44 | 7.11** | 1.55 | 3.19** |
| IPC 15-12 × JAKI-9218 | 2.2 | 3.36 | 1.27 | 6.20* | 1.13** | 1.75* | 7.58 | 1.92 | -2.48 | 3.04 | 0.23 | 3.24 | 3.61** | 0.61 |
| IPC 15-12 × NBEG-3 | 0.95 | 2.36 | -2.02 | -14.81** | -1.41** | -2.53** | -11.86** | -7.45** | -1.29 | -3.34 | -0.09 | -5.35** | -2.07* | -2.45* |
| IPC 15-12 × KATILA | -1.62 | -3.09 | 0.77 | -2.37 | -1.61** | -3.18** | -13.94** | 0.4 | 5.38 | -6.62* | -0.58 | -5.00* | -3.09** | -1.35 |

tential for high-yield breeding. The cross IPC 12-211 × Katila displayed the highest SYPP value of 23.28**, with an impressive heterosis of 41.58%, making it one of the most promising combinations for yield improvement [3].

The crosses like JG 11 × JAKI-9218 also exhibit significant SYPP results with a value of 15.15, and it achieved 41.09% superiority in SH. Additionally, IPC 12-211 × JAKI-9218 performed exceptionally well, registering a SYPP of 10.00 and a superiority of 36.14% in SH. These combinations demonstrate excellent potential for maximizing yield, particularly in hybridization programs targeting improvements in seed production [5, 6].

However, not all crosses were favorable for SYPP. For instance, PBG 8 × JAKI-9218 showed a significantly negative SYPP value of -10.74 with a negative heterosis of -9.74% over the better parent (BP). Similarly, BGD-72 × Katila had a SYPP value of -9.96, indicating poor performance in this combination. These results suggest certain crosses require careful evaluation for yield improvement as their yield contributing role is not very clear [18].

## Conclusion

This study highlights the significant role of genetic diversity and combining ability in enhancing chickpea yield and related traits. The evaluation of general and SCA identified superior parental lines and cross combinations that can be utilized in breeding programs. Crosses such as PBG 7 × NBEG-3 and IPC 12-211 × Katila demonstrated exceptional yield potential, making them ideal candidates for increasing productivity in chickpea. The findings also emphasize the impor-

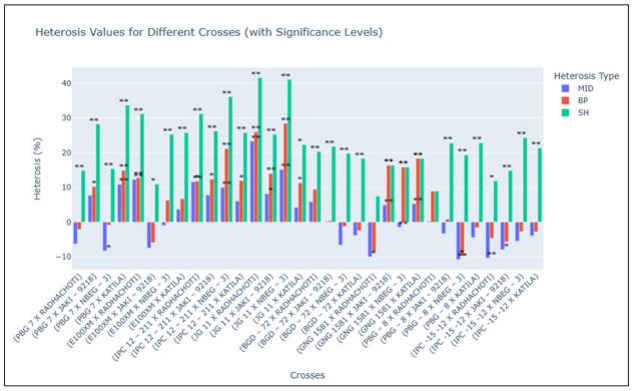


**Figure 1:** Magnitude of mid parent, BP, and SH of SYPP.

tance of both additive and non-additive genetic effects in trait expression. While some crosses exhibited negative heterosis for certain traits, strategic selection of PG based on combining ability effects offers a viable path for optimizing chickpea breeding. These insights provide a valuable foundation for future research aimed at improving chickpea yields and agricultural performance.

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## Conflict of Interest

None.

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