International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2025): 5.29
IJABR 2025; SP-9(10): 237-240
www.biochemjournal.com
Received: 15-08-2025
Accepted: 20-09-2025

Assessment of heterosis and inbreeding depression for yield and its component traits in pigeonpea [*Cajanus cajan* (L.) Millsp.]

KM Akbari, DA Chauhan, AR Pathak, Shivangi Vanapariya and Yogesh Kashyap

KM Akbari
Department of Genetics and Plant Breeding, N. M. College of Agriculture, Navsari Agricultural University, Navsari, Gujarat, India

Dr. DA Chauhan
Pulses and Castor Research Station, Navsari Agricultural University, Navsari, Gujarat, India

Dr. AR Pathak
Pulses and Castor Research Station, Navsari Agricultural University, Navsari, Gujarat, India

Shivangi Vanapariya
Department of Genetics and Plant Breeding, N. M. College of Agriculture, Navsari Agricultural University, Navsari, Gujarat, India

Yogesh Kashyap
Department of Genetics and Plant Breeding, N. M. College of Agriculture, Navsari Agricultural University, Navsari, Gujarat, India

Corresponding Author:
KM Akbari
Department of Genetics and Plant Breeding, N. M. College of Agriculture, Navsari Agricultural University, Navsari, Gujarat, India

DOI: https://www.doi.org/10.33545/26174693.2025.v9.i10Sc.5933

Abstract
Pigeonpea [*Cajanus cajan* (L.) Millsp.] is an important protein-rich pulse crop with multipurpose uses, crucial for food and nutritional security in India. The present study evaluated heterosis and inbreeding depression in four F_1 hybrids-Cross I (GT-288A × NPR-10), Cross II (GNP-3A × NPR-20), Cross III (GNP-4A × NPR-21) and Cross IV (GNP-5A × NPR-17) developed using CMS lines and fertility restorer lines. F_1 and F_2 generations were assessed for ten agronomic traits during *Kharif* 2024. Significant positive heterosis and heterobeltiosis were observed for pods per plant, seed yield per plant and other yield-related traits, whereas early flowering and maturity exhibited negative heterosis, indicating potential for earliness. Positive inbreeding depression in F_2 revealed the breakdown of favourable gene combinations, suggesting non-additive gene action (dominance and epistasis) governing these traits. Among the crosses, GNP-5A × NPR-17 showed the highest heterosis and heterobeltiosis for seed yield and associated traits, highlighting its promise for hybrid development. These findings provide valuable insights into the genetic control of key agronomic traits in pigeonpea and underscore the importance of exploiting heterosis in breeding programs. The findings underscore the importance of exploiting heterosis to develop high-yielding, stable and genetically improved pigeonpea hybrids, contributing to enhanced productivity and sustainability in pulse production.

Keywords: Heterobeltiosis, inbreeding depression, mid parent heterosis, pigeonpea

Introduction

India has achieved self-sufficiency in food production following the Green Revolution, yet protein and calorie malnutrition remains a major concern. Pulses and oilseeds are essential sources of proteins and fats, yet their production falls short of national demand, highlighting the need for effective strategies to enhance pulse productivity (Choudhry and Singh, 2011) [8].

Pigeonpea [*Cajanus cajan* (L.) Millsp.] locally known as Arhar, Red gram and Tur is a multipurpose, protein rich major *kharif* crop cultivated widely across the world. It is ranked as second important pulse crop of India after chickpea. It is an often-cross pollinated crop (20-70%) with 2n = 22 chromosomes and a genome size of 833.1 Mbp, belonging to the family *Fabaceae* (Varshney *et al*., 2012) [20]. In India, two distinct varieties of pigeonpea have been grown *viz*., *Cajanus cajan* var. *bicolor* (arhar) and *Cajanus cajan* var. *flavus* (tur). As a significant pulse crop, pigeonpea plays a vital role in ensuring food and nutritional security for the Indian population (Saxena *et al*., 2015) [18]. Once considered an orphan crop, pigeonpea has emerged as a vital lifeline for millions of resource-poor farmers in the arid and semi-arid tropics.

Pigeonpea is a hard-woody shrub that thrives across a wide range of soils and climatic conditions. It enriches the soil by contributing 40-60 kg/ha of nitrogen to the subsequent crops (Sarkar *et al*., 2020) [16]. It is a nutrient-rich crop, providing substantial amounts of protein, carbohydrates, lipids, vitamins and minerals. As a versatile legume, it provides grains for food, green pods as vegetables, leaves for fodder and wood for fuel. Its resilience and multipurpose nature make it particularly valuable for resource-poor farmers (Verma *et al*., 2018) [21].

The exploitation of heterosis has emerged as one of the most promising strategies for achieving substantial improvements in crop yield. A breeding approach based on hybridization offers great potential to break yield barriers and improve productivity in pigeonpea. Heterosis expresses the superiority of F_1 hybrid over its parents in terms of yield and other traits. Heterosis indicates genetic diversity within the germplasm and aids in selecting ideal parents for superior F_1 hybrids. Its exploitation depends on the magnitude of relative heterosis (over mid-parents), heterobeltiosis (over better parents) and standard heterosis (over the check variety) in the gene pool. Heterosis can be positive or negative and both forms are valuable in crop improvement depending on the trait and breeding objectives. On the other hand, inbreeding depression refers to a decrease in fitness and vigour due to continuous inbreeding and decreased heterozygosity. It results from the fixation of unfavourable recessive genes in F_2, while in heterosis, undesirable recessive genes of one parent are suppressed by favourable dominant genes of another parent. Strategic combination of genetically diverse parents and minimizing inbreeding allows effective exploitation of heterosis and reduces the risks of inbreeding depression. This approach facilitates the development of superior hybrid varieties with stable and enhanced yields. Therefore, the present study was undertaken to evaluate heterosis and inbreeding depression for improving various traits in pigeonpea.

Materials and Methods

The genotypes GT-288A, GNP-3A, GNP-4A and GNP-5A were CMS lines derived from the A_2 cytoplasm (*Cajanus scarabaeoides*) and it served as the female parent in the crossing program. In contrast, NPR-10, NPR-20, NPR-21 and NPR-17 were employed as male parents, as these are well-known fertility restorer lines capable of restoring fertility in hybrid combinations. These eight parents were selected and crossed for generation mean analysis, leading to the development of four F_1s-cross I (GT-288A × NPR-10), cross II (GNP-3A × NPR-20), cross III (GNP-4A × NPR-21) and cross IV (GNP-5A × NPR-17) were developed at the Pulses and Castor Research Station, Navsari Agricultural University, Navsari during *Kharif* 2022. The F_1 hybrids were selfed during *Kharif* 2023 to obtain F_2 seeds for each cross. The seeds of each parental line along with the F_1 and F_2 generations of the respective crosses were harvested separately. The seeds of all generations from the four crosses were evaluated during *Kharif* 2024. Inter and intra row spacing was 90 cm and 20 cm, respectively. All recommended agronomic practices and necessary plant protection measures were timely adopted to ensure healthy crop growth. The observations were recorded based on ten randomly selected competitive plants for various ten characters *i.e.*, days to 50% flowering, days to maturity, plant height, primary branches per plant, secondary branches per plant, pods per plant, pod length, seeds per pod, seed yield per plant and 100 seed weight. The mean values obtained from the observations were subjected to detailed statistical analysis. Heterosis was calculated as the percentage change of the F_1 hybrid mean over the mid-parent (relative heterosis) according to Briggle (1963) [6] and over the better parent (heterobeltiosis) following Fonseca and Patterson (1968) [9]. Inbreeding depression was estimated by measuring the reduction in performance or vigour of the F_2 generation compared to the F_1 generation.

Results and Discussion

The present study aimed to evaluate heterosis and inbreeding depression in pigeonpea for the development of high-yielding, stable and genetically improved hybrid varieties. The expression of heterosis in percentage over mid parent (relative heterosis) and over better parent (heterobeltiosis) as well as estimates of inbreeding depression of four crosses were studied for ten characters and have been given in Table-1. Cross I (GT-288A × NPR-10), cross II (GNP-3A × NPR-20), cross III (GNP-4A × NPR-21) and cross IV (GNP-5A × NPR-17) hereafter designated as cross I, cross II, cross III, and cross IV, respectively.

The magnitude of heterosis indicated that none of the crosses showed significant heterosis for all the characters over both mid and better parents. The extent and direction of heterotic effects varied across characters as well as among the different crosses. However, a considerable amount of desirable and significant heterosis over the mid-parent was observed for most traits. Earliness and early maturity most desirable characters for pigeonpea. Significant and negative heterosis over mid parent was observed in three crosses (Cross-I, II and III) for days to 50% flowering and days to maturity, highlighting their potential for developing early flowering and early maturing pigeonpea hybrids. For days to 50% flowering and days to maturity heterosis in both negative and positive direction were also evident by Koli *et al*. (2025) [11], Chandra *et al*. (2024) [7], Bisht *et al*. (2023) [5] and Saxena *et al*. (2021) [17]. Significant and desirable heterosis over mid parent was observed in three crosses (Cross-I, II and III) for plant height, indicating their promise for improving plant stature. These results are consistent with those reported by Koli *et al*. (2025) [11], Aarif *et al*. (2022) [1], Puttawar *et al*. (2018) [14] and Ashutosh *et al*. (2017) [3]. One cross (cross-II) for primary branches per plant and one cross (cross-III) for secondary branches per plant showed significant and positive relative heterosis, suggesting its potential for improving this trait through hybrid development. Similar results were reported by Ranjani *et al*. (2023) [15], Patel *et al*. (2020) [13] and Jadhav *et al*. (2016) [10]. All four crosses (Cross-I, II, III and IV) exhibited significant and positive heterosis for pods per plant and seed yield per plant, indicating their strong potential for yield improvement in pigeonpea. These findings are consistent with earlier reports by Koli *et al*. (2025) [11], Patel *et al*. (2020) [13], Puttawar *et al*. (2018) [14], Ashutosh *et al*. (2017) [3] and Jadhav *et al*. (2016) [10]. Cross IV exhibited desirable heterosis for pod length, while three crosses (cross-II, III and IIV) recorded significant and positive heterosis for seeds per pod, reflecting their usefulness in improving yield-contributing traits. These results correspond with previous observations made by Koli *et al*. (2025) [11], Patel *et al*. (2020) [13], Puttawar *et al*. (2018) [14] and Jadhav *et al*. (2016) [10]. Three crosses (Cross-I, II and III) exhibited significant positive heterosis for 100-seed weight, indicating their potential in enhancing seed size and overall productivity. These results are in line with earlier reports by Patel *et al*. (2020) [13], Puttawar *et al*. (2018) [14], Ashutosh *et al*. (2017) [3] and Jadhav *et al*. (2016) [10].

Significant and desirable heterobeltiosis was observed in one cross (cross II) for days to 50% flowering and days to maturity, indicating enhanced earliness as the hybrid flowered and matured earlier than the better parent. Significant and positive heterobeltiosis was observed for plant height in two crosses (Cross-I and II), for primary branches per plant in one cross (cross-II) and for secondary branches per plant in one cross (cross-III), indicating superiority over the better parent. All four crosses (Cross-I, II, III and IV) exhibited positive and significant heterobeltiosis for pods per plant, while pod length and seeds per pod showed significance in cross IV and cross II, respectively, suggesting that these hybrids outperformed their respective better parents. Moreover, all crosses recorded desirable heterobeltiosis for seed yield per plant and one cross showed significance for 100 seed weight, highlighting their superiority over their respective better parents. These results are consistent with those documented Koli *et al*. (2025) [11], Chandra *et al*. (2024) [7], Bisht *et al*. (2023) [5], Ranjani *et al*. (2023) [15], Aarif *et al*. (2022) [1], Bhati *et al*. (2020) [4], Patel *et al*. (2020) [13], Puttawar *et al*. (2018) [14] and Jadhav *et al*. (2016) [10].

Inbreeding depression in F_2 generation was estimated for all the characters under study. Positive and significant inbreeding depression was recorded in two crosses (cross-II and IV) for days to 50% flowering and in one cross (cross-IV) for days to maturity, indicating a favourable shift toward earliness. The presence of inbreeding depression for days to 50% flowering and days to maturity was also reported by Bisht *et al*. (2023) [5], Bhati *et al*. (2020) [4] and Parmar and Kathiria (2016) [12]. All four crosses exhibited non-significant inbreeding depression for plant height, primary branches per plant and pod length, indicating minimal loss of hybrid vigour due to inbreeding. These results are in agreement with the findings of Parmar and Kathiria (2016) [12], Jadhav *et al*. (2016) [10], Singh and Singh (2016) [19] and Ajay *et al*. (2015) [2]. A positive and significant inbreeding depression was observed in cross III for secondary branches per plant, in cross IV for pods per plant, in two cross III and IV for seeds per pod, in cross II, III and IV for seed yield per plant and in cross I, III and IV for 100 seed weight, indicating loss of hybrid performance in the F_2 generation due to the breakdown of favourable gene interactions. Similar observations have been reported by Bisht *et al*. (2023) [5], Bhati *et al*. (2020) [4], Jadhav *et al*. (2016) [10], Parmar and Kathiria (2016) [12] and Singh and Singh (2016) [19].

The combined estimates of heterosis and inbreeding depression provide insights into the type of gene action governing the expression of quantitative traits. High heterosis followed by significant inbreeding depression indicates the predominance of non-additive gene action, such as dominance and epistasis, where selection will be effective only in latter generations. Similar performance in F_1 and F_2 generations indicates that additive gene action predominantly governs the trait. Conversely, negative heterosis in F_1 followed by an increase in F_2 also points to additive gene effects.

Table 1: Estimates of relative heterosis (RH %), heterobeltiosis (HB %) and inbreeding depression (ID %) for days to 50% flowering, days to maturity, plant height (cm), primary branches per plant, secondary branches per plant in four crosses of pigeonpea

Particulars	Days to 50% flowering		Days to maturity		Plant height (cm)		Primary branches per plant		Secondary branches per plant	
Cross I (GT-288A × NPR-10)										
	Estimates	**SE**	**Estimates**	**SE**	**Estimates**	**SE**	**Estimates**	**SE**	**Estimates**	**SE**
RH %	-3.05**	±0.50	-1.48**	±0.48	11.78**	±2.27	9.54	±0.26	-6.56	±0.77
HB %	1.20*	±0.53	2.99**	±0.53	2.39	±2.66	-14.37**	±0.31	-15.16**	±1.03
ID %	-2.33**	±0.64	-1.37**	±0.44	2.70	±2.84	3.55	±0.26	6.22	±0.73
Cross II (GNP-3A × NPR-20)										
RH %	-3.69**	±0.33	-2.94**	±0.37	13.21**	±2.09	14.81**	±0.38	1.37	±0.63
HB %	-2.67**	±0.37	-2.20**	±0.41	7.23**	±2.42	9.62*	±0.47	-6.48*	±0.67
ID %	1.44**	±0.47	-1.09**	±0.45	-0.81	±2.73	-1.20	±0.42	-2.24	±0.65
Cross III (GNP-4A × NPR-21)										
RH %	-2.22**	±0.36	-0.84**	±0.47	5.00**	±2.02	0.38	±0.38	20.45**	±0.46
HB %	1.28**	±0.37	2.31**	±0.51	-5.46**	±2.33	-6.69	±0.45	10.88**	±0.57
ID %	-2.74**	±0.49	-1.92**	±0.50	-3.27	±2.67	4.72	±0.37	8.88**	±0.51
Cross IV (GNP-5A × NPR-17)										
RH %	0.40	±0.41	4.20**	±0.37	1.59	±2.11	-3.59	±0.53	3.51	±0.53
HB %	2.90**	±0.45	7.31**	±0.41	-3.84**	±2.39	-12.37*	±0.59	-7.26*	±0.63
ID %	1.65**	±0.44	1.32**	±0.38	-2.47	±2.06	7.84	±0.52	-12.04**	±0.54

Table 2: Estimates of relative heterosis (RH %), heterobeltiosis (HB %) and inbreeding depression (ID %) for pods per plant, pod length (cm), seeds per pod, seed yield per plant (g) and 100 seed weight (g) in four crosses of pigeonpea

Particulars	Pods per plant		Pod length (cm)		Seeds per pod		Seed yield per plant (g)		100 seed weight (g)	
Cross I (GT-288A × NPR-10)										
	Estimates	**SE**	**Estimates**	**SE**	**Estimates**	**SE**	**Estimates**	**SE**	**Estimates**	**SE**
RH %	14.46**	±4.80	0.30	±0.10	0.78	±0.11	17.75**	±0.90	3.94**	±0.07
HB %	8.09**	±5.16	-5.05**	±0.11	-7.19**	±0.12	11.19**	±0.96	-5.04**	±0.08
ID %	-3.75	±5.69	4.30*	±0.10	-5.62*	±0.10	-0.85	±1.04	5.04**	±0.08
Cross II (GNP-3A × NPR-20)										
RH %	13.72**	±4.33	3.19	±0.10	18.18**	±0.10	18.28**	±0.78	1.34**	±0.05
HB %	7.63**	±5.37	-4.57**	±0.12	9.16**	±0.12	11.94**	±0.99	-5.24**	±0.07
ID %	1.90	±4.30	4.79**	±0.10	5.07*	±0.10	5.67**	±0.78	-2.81**	±0.05
Cross III (GNP-4A × NPR-21)										
RH %	6.68**	±4.36	2.35	±0.13	13.54**	±0.12	20.85**	±0.86	7.85**	±0.07
HB %	2.72	±4.86	-4.92*	±0.15	4.84	±0.15	16.37**	±0.94	3.91**	±0.08
ID %	-4.73*	±4.15	4.65*	±0.13	-4.81	±0.11	7.55**	±0.82	3.34**	±0.08
Cross IV (GNP-5A × NPR-17)										
RH %	16.46**	±3.51	13.02**	±0.10	5.22*	±0.11	16.46**	±0.70	-0.19	±0.05
HB %	8.57**	±4.16	8.67**	±0.12	-4.08	±0.12	8.57**	±0.83	-7.23**	±0.06
ID %	3.72*	±3.69	9.55**	±0.09	6.92**	±0.10	3.72*	±0.74	4.81**	±0.09

Conclusion
Highly significant and positive value for heterosis, heterobeltiosis and inbreeding depression were found in many crosses. For seed yield per plant, GNP-5A × NPR-17 was identified as the most promising heterotic combination. This hybrid also exhibited significant standard heterosis and heterobeltiosis in the desirable direction, particularly for important yield-contributing traits such as the number of pods per plant and pod length. The crosses that exhibited high heterosis for seed yield per plant and their associated traits also showed significant inbreeding depression, indicating the presence of strong non-additive gene action. This pronounced heterotic effect was mainly due to the influence of dominance and epistatic interactions governing these characters. Such hybrids not only offer immediate potential for higher productivity but also serve as valuable genetic material for further breeding programs. Moreover, these findings emphasize the importance of exploiting heterosis in pigeonpea to achieve substantial improvements in yield and other agronomic traits, which can contribute to enhancing food security and sustainability in pulse production.

Acknowledgement
Gratefully acknowledge Navsari Agricultural University for providing financial support for this study.

References
1. Aarif M, Sharma S, Sharma M, Tak Y. Implication of hybrid vigour in pigeonpea (*Cajanus cajan* (L.) Millsp.). Front Crop Improv. 2022;9:2837-2843.
2. Ajay BC, Byregowda M, Veerakumar GN, Reena M, Babu HP, Ganapathy KN. Heterosis and inbreeding depression for yield attributing characters in F2 and F3 generations of pigeonpea. Natl Acad Sci Lett. 2015;38(2):179-181.
3. Ashutosh A, Bhanu A, Singh MN. Gene effects for yield contributing characters in long duration pigeonpea (*Cajanus cajan* (L.) Millsp.). Indian J Pure Appl Biosci. 2017;5(5):1615-1618.
4. Bhati K, Chauhan DA, Rathod KC, Patel AD. A study of heterosis and inbreeding depression in pigeonpea (*Cajanus cajan* (L.) Millsp.). Int J Chem Stud. 2020;8(5):2643-2648.
5. Bisht C, Verma SK, Gaur AK, Yadav H, Deep H, Chauhan C, *et al*. Combining ability, genetic diversity and their association with heterosis for seed yield in pigeonpea (*Cajanus cajan* (L.) Millsp.). Legume Res. 2023;46(12):1571-1577.
6. Briggle LW. Heterosis in wheat-A review. Crop Sci. 1963;3:407-412.
7. Chandra D, Verma SK, Gaur AK, Bisht C, Gautam A, Chauhan C, *et al*. Heterosis, combining ability, genetic diversity and their interrelationship in pigeonpea (*Cajanus cajan* (L.) Millsp.). Legume Res. 2024;47(2):183-189.
8. Choudhary AK, Singh D. Screening of pigeonpea genotypes for nutrient uptake efficiency under aluminium toxicity. Physiol Mol Biol Plants. 2011;17(2):145-152.
9. Fonseca S, Patterson FL. Hybrid vigour in a seven parental diallel cross in common winter wheat (*Triticum aestivum* L.). Crop Sci. 1968;8(1):85-88.
10. Jadhav AT, Gite VK, Patil DK, Surashe SM. Study on heterosis for yield and yield component traits in pigeonpea (*Cajanus cajan* (L.) Millsp.). Int J Agric Sci. 2016;11(6):4185-4191.
11. Koli HK, Sharma SC, Koli NR, Sharma MK, Meena CB, Meena RK, *et al*. Heterosis analysis for seed yield and biochemical attributes in pigeonpea (*Cajanus cajan* (L.) Millsp.). Plant Arch. 2025;25(1):563-571.
12. Parmar MB, Kathiria KB. Genetic analysis of seed yield and quantitative traits in pigeonpea. Glob J Res Anal. 2016;5(2):182-186.
13. Patel H, Chaudhary N, Patel A, Kugashiya K. Exploitation of heterosis in hybrids developed using cytoplasmic genetic male sterility (CGMS) system in pigeonpea (*Cajanus cajan* (L.) Millsp.). J Pharmacogn Phytochem. 2020;9(4):1147-1151.
14. Puttawar MR, Kalpade HV, Patil AE, Naware MS. Implication of combining ability and *per se* performance in pigeonpea (*Cajanus cajan* (L.) Millsp.). J Soils Crops. 2018;28(2):413-420.
15. Ranjani MS, Jayamani P. Identification of fertility restorers for A2 cytoplasm-based CGMS lines and development of short duration hybrids in pigeonpea (*Cajanus cajan* (L.) Millsp.). J Genet. 2023;102(1):28-34.
16. Sarkar S, Mishra SP, Tripathi D, Patidar B, Soni M, Mishra S. Studies on genetic variability, heritability and genetic advance in pigeonpea (*Cajanus cajan* (L.) Millsp.). Int J Curr Microbiol Appl Sci. 2020;9(10):2570-2578.
17. Saxena RK, Jiang Y, Khan AW, Zhao Y, Kumar Singh V, Bohra A, *et al*. Characterization of heterosis and genomic prediction-based establishment of heterotic patterns for developing better hybrids in pigeonpea. Plant Genome. 2021;14(3):e20125.
18. Saxena RK, Saxena KB, Pazhamala LT, Patel K, Parupalli S, Sameerkumar CV, *et al*. Genomics for greater efficiency in pigeonpea hybrid breeding. Front Plant Sci. 2015;6:793-801.
19. Singh RS, Singh MN. Heterosis and inbreeding depression for yield and yield traits in pigeonpea (*Cajanus cajan* (L.)). Environ Ecol. 2016;34(1A):395-399.
20. Varshney RK, Chen W, Li Y, Bharti AK, Saxena RK, Schlueter JA, *et al*. Draft genome sequence of pigeonpea (*Cajanus cajan*), an orphan legume crop of resource-poor farmers. Nat Biotechnol. 2012;30(1):83-89.
21. Verma SK, Bisht C, Gaur AK, Chandra D. Study on some genetic parameters for yield and related traits in pigeonpea (*Cajanus cajan* (L.) Millsp.) genotypes. Chem Sci Rev Lett. 2018;7(25):70-76.