International Journal of Advanced Biochemistry Research

**ISSN Print:** 2617-4693
**ISSN Online:** 2617-4707
IJABR 2025; SP-9(1): 598-607
www.biochemjournal.com
Received: 08-11-2024
Accepted: 13-12-2024

**BL Pandor**
Department of Genetics and Plant Breeding, B. A. College of Agriculture, Anand, Gujarat, India

**MP Patel**
Regional Research Station, Anand Agricultural University, Anand, Gujarat, India

**RH Chaudhari**
Department of Agricultural Statistics, B. A. College of Agriculture, Anand, Gujarat, India

**Corresponding Author:**
**BL Pandor**
Department of Genetics and Plant Breeding, B. A. College of Agriculture, Anand, Gujarat, India

# Heterosis analysis for seed yield and its component characters in castor [*Ricinus communis* L.]

**BL Pandor, MP Patel and RH Chaudhari**

**DOI:** https://doi.org/10.33545/26174693.2025.v9.i1Sh.3575

**Abstract**
Investigation of 61 genotypes, representing 3 diverse pistillate lines, 14 testers, their 42 $F_1$s(developed by Lines × Testers mating design) and 2 standard check hybrids (GCH 7 and GNCH 1) was carried out to determine the extent of heterosis for seed yield and its components traits. Randomized Complete Block Design was used to assess the experimental material using three replications. It would be preferable to select crosses based on *per se* performance with significant percent heterobeltiosis and standard heterosis in order to generate genotypes with high yields and early maturation. High heterobeltiosis, standard heterosis, and positive highest sca effects for seed yield were recorded by the hybrids Geeta × SKI 343, Geeta × SKI 315, Geeta × ANDCI 12-2, SKP 84 × ANDCI 14, and Geeta × SKI 215. These hybrids may be directly exposed for commercial cultivation and may be advanced for the development of parental genotypes.

**Keywords:** Castor, heterobeltiosis, standard heterosis and seed yield

## Introduction

Castor (*Ricinus communis* L.) appertains to family Euphorbiaceae. The castor has a chromosomal count of 2n = 20, and it is heavily cross-pollinated, up to 50 percent. It is indigenous to Eastern Africa and most probably originated in Ethiopia. Although it is a semi-tropical, indeterminate perennial plant, it has spread throughout the world's frost-free zones as an annual or seasonal agricultural plant. It is best suited for dry land farming since it can thrive in environments with limited fertility and rainfall. It has a significant economic impact on the country's arid and semi-arid regions due to its hardiness. India leads global castor production, surpassing the world average, and ranks first among major castor-producing nations such as China, Brazil, and Thailand. The country cultivates castor across 0.89 million hectares, yielding a production of 1.51 million tons and a productivity of 1697 kg/ha (Anonymous, 2023) [1]. Gujarat is the dominant state for castor cultivation, followed by Andhra Pradesh, Telangana, Tamil Nadu, Rajasthan, and Madhya Pradesh. Castor oil serves as an effective laxative and is also used to treat various skin conditions, including sunburn, wrinkles, and stretch marks. The by-product of castor oil extraction, known as castor cake, is a valuable organic fertilizer, rich in nitrogen (6.4%), $P_2O_5$ (2.5%), $K_2O$ (1%), and essential micronutrients, making it ideal for organic farming. Additionally, castor plant stems are used as firewood and to produce paper pulp, while fresh castor leaves support silkworm rearing, and dried leaves are utilized as a natural insecticide in agriculture.

The nature and extent of heterosis play a crucial role in selecting the appropriate parent plants for crosses and in identifying superior cross combinations that may yield desirable transgressive segregants in subsequent generations. For breeders, choosing the right parents for a hybridization program is a vital step, especially when the goal is to improve complex quantitative traits like yield and its components. Selecting parents with proven superior genetic traits significantly enhances the likelihood of success. This process requires a thorough genetic evaluation of both existing germplasm and newly developed promising genotypes, which may be used in future breeding programs or potentially released as new cultivars after rigorous testing. To improve the yield potential of varieties and hybrids, careful consideration must be given to the selection of parents for hybridization. While performance per se is a common selection criterion, obtaining detailed information about the magnitude of heterosis for seed yield and its component traits, as well as understanding the inheritance patterns in different parents and their crosses, can be instrumental in selecting the most appropriate parents and desirable cross combinations for the commercial exploitation of hybrid vigor.

## Materials and Methods

The experimental material for the present investigation was generated by crossing germplasm lines collected from different parts of country. Three diverse lines namely VP 1, SKP 84 and Geeta and fourteen testers namely ANDCI 1, ANDCI 8, ANDCI 14, ANDCI 10-3, ANDCI 10-5, ANDCI 12-2, 48-1, RB 1, DCS 109, DCS 97, SKI 215, GP 640, SKI 315 and SKI 343 were crossed according to L x T mating design during *kharif* 2016-17 to obtain 42 $F_{1S}$. These 42 $F_{1S}$ and their parents and checks GCH 7, the most successful hybrid and GNCH 1 were evaluated during *kharif* 2017-18. Seventeen parents, their hybrids and two checks were raised in a randomized complete block design in three replications at Regional Research Station, Anand Agricultural University, Anand. Ten seeds of each entry was dibbled in a 6 meter long row with inter and intra row spacing of 120 × 60 cm. Recommended agronomic practices were followed to grow a healthy crop.

Data were collected on several traits, including days to 50 percent flowering, number of nodes up to the primary raceme, days to maturity of the primary raceme, plant height up to the primary raceme (cm), total length of the primary raceme (cm), effective length of the primary raceme (cm), number of capsules on the primary raceme, effective number of spikes per plant, seed yield per plant (g), shelling out-turn (%), 100-seed weight (g), and oil content (%). For each genotype, observations were made on five randomly selected plants per replication for each of the 12 traits, and the average value per plant was calculated, except for days to 50 percent flowering and days to maturity of the primary raceme. These two traits were recorded on a population basis.

The mean values for all traits across the different replications were analyzed using the analysis of variance method outlined by Snedecor and Cochran (1967) [9] and later reviewed by Panse and Sukhatme (1978) [5], to assess the significance of differences between genotypes. Standard heterosis and heterobeltiosis were calculated following the procedure proposed by Shull (1952) [10].

## Results and Discussions

### 1.1 Analysis of variance for experimental design

Analysis of variance was conducted to evaluate the differences between parents and hybrids for all twelve traits, with the results presented in Table 1. The findings showed that the mean square values for genotypes were highly significant across all traits, indicating substantial genetic variability within the experimental material. Parental genotypes exhibited significant differences for all traits, except for shelling out-turn. When examining the variance due to parental genotypes, both lines and testers differed significantly for all traits, except for seed yield per plant for lines and shelling out-turn for both lines and testers. Significant differences were found among hybrids for all traits, and significant differences between parents and hybrids were observed for all traits, except for the total length of the primary raceme, effective length of the primary raceme, and effective number of spikes per plant. This suggests the presence of heterotic effects for all traits. Additionally, significant mean squares for check versus hybrids were observed for days to 50% flowering, number of nodes up to the primary raceme, days to maturity of the primary raceme, total length of the primary raceme, number of capsules on the primary raceme, and effective number of spikes per plant, indicating that the F1s differed significantly from the check hybrids.

### 1.2 Magnitude of heterosis

The extent and magnitude of various heterotic effects, expressed as percentages over the better parent (HB) and over check hybrids (SH), varied across different crosses and traits. In this study, the degree of heterosis differed from one cross to another and from one trait to another. For specific traits, some crosses exhibited significant heterotic effects, while others showed lower effects, indicating that the nature of gene action was influenced by the genetic composition of the parent genotypes. Several crosses in this investigation demonstrated notable heterotic responses, both over the better parental value (heterobeltiosis) and over standard check hybrids (standard heterosis), such as GCH 7 and GNCH 1. The commercial potential of these hybrids largely depends on their performance relative to the best existing hybrid in the crop.

Seed yield is the economic important trait and breeders attempt to evolve varieties/hybrids with high seed yield. The results (table 2.) revealed that heterosis over better parent ranged from -52.95 (VP 1 × ANDCI 10-3) to 78.91 (Geeta × SKI-343) percent; while, standard heterosis over GCH 7 (best check) varied from -55.58 (VP 1 × ANDCI 10-5) to 70.89 (Geeta × SKI 315) percent. As many as 13and 9 hybrids registered significant positive heterobeltiosis and standard heterosis, respectively. The cross combinations Geeta × SKI-343 (78.91%), Geeta × SKI 315 (76.37%), Geeta × ANDCI 12-2 (57.01%), SKP 84 × ANDCI 14 (55.35%) and Geeta × SKI 215 (48.54%) exhibited higher estimates of heterobeltiosis and standard heterosis over best check.As observed in the present investigation, several workers have also reported the presence of considerable degree of heterosis for seed yield in castor (Chaudhari and Patel (2014) [2], Dave (2015) [3], Sapovadia (2015) [8], Kugashiya *et al*. (2017) [4] and Punewar *et al*. (2017) [7] for heterobeltiosis. Whereas, the results differed from the findings of Thakker (2002) [11] and Thakker *et al*. (2005a) [12] as they observed only positive magnitude for both HB and SH).Whereas for days to 50 percent flowering and days to maturity of primary raceme hybridVP 1 × ANDCI 8found most promising.

Large number of crosses exhibited significant and desirable heterotic effects (HB and SH) for growth attributes *viz*.; days to 50 percent flowering, number of nodes upto primary raceme, plant height upto primary racemeand days to maturity of primary raceme as well as yield attributes *viz*.;number of capsules on primary raceme, effective number of spikes per plantand 100 seed weight.

A total of 13 and nine crosses showed higher estimates of heterobeltiosis and standard heterosis, respectively, for seed yield. Most of these crosses exhibited significant and positive heterotic effects for traits such as the number of capsules on the primary raceme, the effective number of spikes per plant, and 100-seed weight. This suggests that the heterotic effects on seed yield per plant could be attributed to the direct influence of these traits. Additionally, developmental characteristics like days to 50% flowering, the number of nodes up to the primary raceme, plant height at the primary raceme, and days to maturity of the primary raceme may have contributed indirectly. Consequently, the heterotic effects for seed yield per plant may result from both direct and indirect influences of various yield-contributing traits. On the other hand, the positive and negative heterosis estimates for other component traits might have balanced each other, resulting in the observed net heterotic effects for seed yield. To achieve maximum heterotic effects for seed yield, it is essential to determine the desired level of heterosis for each contributing trait.

Among the parental genotypes, pistillate lines Geeta and SKP 84 and inbred lines SKI 343, SKI 315, ANDCI 12-2, ANDCI 14 and SKI 215 yielded the superior heterotic combination for seed yield per plant.

The top five promising crosses for seed yield per plant were compared based on their per se performance, SCA effects, and percentage heterosis over the better parent and the standard check GCH 7 across various traits (Tables 2.1 to 2.6). A comparative analysis of these heterotic crosses and their yield components is summarized in Table 3. The results highlighted that the crosses Geeta × SKI 343, Geeta × SKI 315, Geeta × ANDCI 12-2, SKP 84 × ANDCI 14, and Geeta × SKI 215 exhibited superior per se performance. These crosses also demonstrated significant and high positive heterobeltiosis and standard heterosis. Except for Geeta × ANDCI 12-2, all these crosses showed significant and positive SCA effects. These crosses involved G × A types of GCA parental combinations. Among developmental traits, the number of nodes up to the primary raceme, days to maturity of the primary raceme, and plant height up to the primary raceme likely contributed indirectly. Thus, the heterotic effects for seed yield per plant appear to be the result of combinational heterosis. Additionally, the positive and negative heterosis estimates for other traits may have counterbalanced each other, affecting the expression of heterotic effects. To achieve maximum heterotic effects for seed yield, it is important to determine the desired level of heterosis for each contributing trait to identify superior hybrids. These crosses also displayed significant and desirable standard heterosis for the total length of the primary raceme, 100-seed weight, and the effective number of spikes per plant. Therefore, the heterotic effects for seed yield per plant were likely driven by the length of the primary raceme, 100-seed weight, the effective number of spikes per plant, and the indirect influence of other traits.

## Future Breeding Strategy

It can be concluded among 42 hybrids tested, five hybrids *viz.*, Geeta × SKI-343, Geeta × SKI 315, Geeta × ANDCI 12-2, SKP 84 × ANDCI 14 and Geeta × SKI 215 registered high heterobeltiosis, standard heterosis and positive highest sca effects for seed yield along with high *per se* performance may be directly exposed for commercial cultivation and may be advanced for development of parental genotypes.

**Table 1:** Analysis of variances for yield and its components (Mean sum of squares)

| Source of variation | d f | Days to 50 percent flowering | | No. of nodes upto primary raceme | | Days to maturity of primary raceme | | Plant height upto primary raceme | | Total length of primary raceme | | Effective length of primary raceme | | No. of capsules on primary raceme | | Effective no. of spikes per plant | | Seed yield per plant | | Shelling out-turn | | 100 seed weight | | Oil content | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Replications | 2 | 15.74 | | 5.19 | ** | 157.14 | ** | 99.08 | | 3.23 | | 23.90 | * | 99.08 | | 0.24 | | 2031.61 | | 100.82 | | 2.44 | | 7.89 | ** |
| Genotypes | 60 | 70.92 | ** | 14.61 | ** | 386.62 | ** | 722.45 | ** | 125.16 | ** | 130.09 | ** | 722.45 | ** | 29.14 | ** | 9870.07 | ** | 110.64 | ** | 41.03 | ** | 5.43 | ** |
| Parents | 16 | 38.61 | ** | 17.90 | ** | 339.82 | ** | 622.03 | ** | 215.93 | ** | 220.03 | ** | 622.03 | ** | 10.3 | ** | 1898.38 | ** | 52.92 | | 28.48 | ** | 6.48 | ** |
| Lines | 2 | 96.33 | ** | 56.70 | ** | 1232.11 | ** | 1473.27 | ** | 587.57 | ** | 634.68 | ** | 1473.27 | ** | 10.45 | ** | 1576.22 | | 32.11 | | 50.97 | ** | 6.36 | * |
| Tester | 13 | 29.66 | ** | 10.79 | ** | 223.61 | ** | 497.70 | ** | 174.99 | ** | 170.05 | ** | 497.70 | ** | 9.89 | ** | 1909.23 | ** | 48.60 | | 23.50 | ** | 6.53 | ** |
| Lines *vs.* Testers | 1 | 39.53 | ** | 32.71 | ** | 65.96 | | 535.89 | ** | 4.92 | | 40.46 | * | 535.89 | ** | 15.35 | ** | 2401.68 | | 150.65 | * | 48.15 | ** | 5.98 | * |
| Hybrids | 41 | 71.81 | ** | 11.83 | ** | 343.38 | ** | 773.36 | ** | 97.92 | ** | 103.90 | ** | 773.36 | ** | 38.03 | ** | 13305.25 | ** | 122.09 | ** | 48.06 | ** | 5.03 | ** |
| Parents *vs.* Hybrids | 1 | 57.57 | ** | 58.87 | ** | 898.00 | ** | 775.15 | ** | 0.02 | | 3.38 | | 775.15 | ** | 0.05 | | 16204.12 | ** | 591.47 | ** | 16.87 | ** | 9.41 | ** |
| Checks *vs.* Hybrids | 1 | 654.55 | ** | 7.13 | ** | 3048.58 | ** | 1074.89 | ** | 36.29 | * | 18.64 | | 99.08 | | 0.24 | | 2031.61 | | 100.82 | | 2.44 | | 7.89 | ** |
| Between Checks | 1 | 16.67 | | 43.20 | ** | 66.67 | | 23.34 | | 3.23 | | 4.38 | | 722.45 | ** | 29.14 | ** | 9870.07 | ** | 110.64 | ** | 41.03 | ** | 5.43 | ** |
| Error | 120 | 8.61 | | 0.86 | | 26.29 | | 39.37 | | 7.57 | | 7.04 | | 622.03 | ** | 10.30 | ** | 1898.38 | ** | 52.92 | | 28.48 | ** | 6.48 | ** |

*, ** significant at 5% and 1% levels of significance, respect

**Table 2.1:** Estimates of heterobeltiosis and standard heterosis for days to 50 percent flowering and number of nodes upto primary raceme

| Sr. No. | Hybrids | Days to 50 percent flowering | | | | | | Number of nodes upto primary raceme | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Heterosis over | | | | | | Heterosis over | | | | | |
| | | BP | | $SC_1$ | | $SC_2$ | | BP | | $SC_1$ | | $SC_2$ | |
| 1 | VP 1 × ANDCI 1 | 6.16 | | -23.27 | ** | -19.27 | ** | 1.26 | | -25.72 | ** | -0.74 | |
| 2 | VP 1 × ANDCI 8 | -8.22 | | -33.66 | ** | -30.21 | ** | 1.88 | | -25.27 | ** | -0.13 | |
| 3 | VP 1 × ANDCI 14 | 16.44 | ** | -15.84 | ** | -11.46 | ** | 47.02 | ** | 7.84 | * | 44.12 | ** |
| 4 | VP 1 × ANDCI 10-3 | 3.42 | | -25.25 | ** | -21.35 | ** | -0.50 | | -27.02 | ** | -2.47 | |
| 5 | VP 1 × ANDCI 10-5 | 5.56 | | -24.75 | ** | -20.83 | ** | -9.16 | | -33.37 | ** | -10.95 | * |
| 6 | VP 1 × ANDCI 12-2 | -1.37 | | -28.71 | ** | -25.00 | ** | -6.54 | | -31.45 | ** | -8.38 | |
| 7 | VP 1 × 48-1 | -0.68 | | -28.22 | ** | -24.48 | ** | 11.46 | * | -18.24 | ** | 9.26 | * |
| 8 | VP 1 × DCS 97 | 3.42 | | -25.25 | ** | -21.35 | ** | -1.74 | | -27.92 | ** | -3.68 | |
| 9 | VP 1 × SKI 215 | 10.27 | * | -20.30 | ** | -16.15 | ** | 1.45 | | -25.58 | ** | -0.55 | |
| 10 | VP 1 × GP 640 | 2.74 | | -25.74 | ** | -21.88 | ** | 0.39 | | -28.09 | ** | -3.90 | |
| 11 | VP 1 × SKI 315 | 11.64 | * | -19.31 | ** | -15.10 | ** | -9.00 | | -33.25 | ** | -10.79 | * |
| 12 | VP 1 × SKI 343 | 9.59 | | -20.79 | ** | -16.67 | ** | -8.35 | | -32.77 | ** | -10.16 | * |
| 13 | VP 1 × RB 1 | 6.16 | | -23.27 | ** | -19.27 | ** | -2.60 | | -28.55 | ** | -4.52 | |
| 14 | VP 1 × DCS 109 | 0.00 | | -27.72 | ** | -23.96 | ** | -1.97 | | -28.09 | ** | -3.90 | |
| 15 | SKP 84 × ANDCI 1 | 10.43 | * | -10.89 | ** | -6.25 | | -7.12 | | -12.15 | ** | 17.40 | ** |
| 16 | SKP 84 × ANDCI 8 | 3.07 | | -16.83 | ** | -12.50 | ** | 1.29 | | -9.95 | ** | 20.34 | ** |
| 17 | SKP 84 × ANDCI 14 | 11.66 | ** | -9.90 | ** | -5.21 | | 4.80 | | -8.95 | ** | 21.68 | ** |
| 18 | SKP 84 × ANDCI 10-3 | 11.04 | * | -10.40 | ** | -5.73 | | -18.50 | ** | -20.05 | ** | 6.84 | |
| 19 | SKP 84 × ANDCI 10-5 | 2.78 | | -26.73 | ** | -22.92 | ** | 14.59 | ** | -11.73 | ** | 17.96 | ** |
| 20 | SKP 84 × ANDCI 12-2 | 8.59 | | -12.38 | ** | -7.81 | * | -3.06 | | -3.47 | | 29.01 | ** |
| 21 | SKP 84 × 48-1 | 6.13 | | -14.36 | ** | -9.90 | ** | 0.34 | | -14.67 | ** | 14.03 | ** |
| 22 | SKP 84 × DCS 97 | 0.61 | | -18.81 | ** | -14.58 | ** | -5.73 | | -13.64 | ** | 15.40 | ** |
| 23 | SKP 84 × SKI 215 | 5.52 | | -14.85 | ** | -10.42 | ** | 2.20 | | -2.50 | | 30.29 | ** |
| 24 | SKP 84 × GP 640 | 1.84 | | -17.82 | ** | -13.54 | ** | 5.57 | | -24.38 | ** | 1.06 | |
| 25 | SKP 84 × SKI 315 | 7.98 | | -12.87 | ** | -8.33 | * | 3.29 | | -19.59 | ** | 7.45 | |
| 26 | SKP 84 × SKI 343 | 0.00 | | -19.31 | ** | -15.10 | ** | -1.03 | | -23.87 | ** | 1.73 | |
| 27 | SKP 84 × RB 1 | -11.66 | ** | -28.71 | ** | -25.00 | ** | -4.79 | | -16.36 | ** | 11.77 | * |
| 28 | SKP 84 × DCS 109 | -4.29 | | -22.77 | ** | -18.75 | ** | 10.32 | * | -13.45 | ** | 15.66 | ** |
| 29 | Geeta × ANDCI 1 | -2.87 | | -16.34 | ** | -11.98 | ** | -9.33 | * | -14.23 | ** | 14.62 | ** |
| 30 | Geeta × ANDCI 8 | 16.46 | ** | -5.45 | | -0.52 | | -5.78 | | -16.23 | ** | 11.94 | ** |
| 31 | Geeta × ANDCI 14 | -10.00 | * | -19.80 | ** | -15.63 | ** | 0.41 | | -12.76 | ** | 16.58 | ** |
| 32 | Geeta × ANDCI 10-3 | 10.59 | * | -6.93 | | -2.08 | | -7.19 | * | -8.96 | ** | 21.66 | ** |
| 33 | Geeta × ANDCI 10-5 | 36.11 | ** | -2.97 | | 2.08 | | 3.23 | | -20.48 | ** | 6.27 | |
| 34 | Geeta × ANDCI 12-2 | -6.36 | | -19.80 | ** | -15.63 | ** | -12.59 | ** | -12.95 | ** | 16.33 | ** |
| 35 | Geeta × 48-1 | 6.47 | | -10.40 | ** | -5.73 | | 2.27 | | -13.03 | ** | 16.23 | ** |
| 36 | Geeta × DCS 97 | 2.38 | | -14.85 | ** | -10.42 | ** | -16.95 | ** | -23.92 | ** | 1.67 | |
| 37 | Geeta × SKI 215 | 6.15 | | -5.94 | | -1.04 | | 0.87 | | -3.77 | | 28.60 | ** |
| 38 | Geeta × GP 640 | 6.32 | | -8.42 | * | -3.65 | | 20.17 | ** | -13.91 | ** | 15.04 | ** |
| 39 | Geeta × SKI 315 | -6.55 | | -22.28 | ** | -18.23 | ** | 9.73 | * | -14.58 | ** | 14.16 | ** |
| 40 | Geeta × SKI 343 | -5.92 | | -21.29 | ** | -17.19 | ** | 19.31 | ** | -8.23 | * | 22.64 | ** |
| 41 | Geeta × RB 1 | -10.00 | * | -19.80 | ** | -15.63 | ** | -6.21 | | -17.61 | ** | 10.11 | * |
| 42 | Geeta × DCS 109 | 1.84 | | -17.82 | ** | -13.54 | ** | 7.76 | | -15.46 | ** | 12.97 | ** |
| Range | Min. | -11.66 | | -33.66 | | -30.21 | | -18.50 | | -33.37 | | -10.95 | |
| | Max. | 36.11 | | -2.97 | | 2.08 | | 47.02 | | 7.84 | | 44.12 | |
| S. E.± | | 2.41 | | | | | | 0.73 | | | | | |
| No of significant crosses | | 12 | | 38 | | 33 | | 12 | | 39 | | 27 | |
| Positive | | 9 | | 0 | | 0 | | 7 | | 1 | | 24 | |
| Negative | | 3 | | 38 | | 33 | | 5 | | 38 | | 3 | |

*, **, Significant at 5% and 1% levels of significance, respectively. BP = Better parent, $SC_1$ = Standard heterosis over check hybrid GCH 7 and $SC_2$ = Standard heterosis over check hybrid GNCH 1.

**Table 2.2:** Estimates of heterobeltiosis and standard heterosis for days to maaturity of primary raceme and plant height upto primary raceme

| Sr. No. | Hybrids | Days to maturity of primary raceme | | | | | | Plant height upto primary raceme | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Heterosis over | | | | | | Heterosis over | | | | | |
| | | BP | | $SC_1$ | | $SC_2$ | | BP | | $SC_1$ | | $SC_2$ | |
| 1 | VP 1 × ANDCI 1 | 8.39 | | -25.75 | ** | -21.84 | ** | 122.58 | ** | -27.70 | ** | -4.54 | |
| 2 | VP 1 × ANDCI 8 | -8.76 | | -37.50 | ** | -34.21 | ** | 135.21 | ** | -23.60 | ** | 0.88 | |
| 3 | VP 1 × ANDCI 14 | 22.26 | ** | -16.25 | ** | -11.84 | ** | 134.02 | ** | -23.98 | ** | 0.37 | |
| 4 | VP 1 × ANDCI 10-3 | 12.04 | ** | -23.25 | ** | -19.21 | ** | 119.07 | ** | -28.84 | ** | -6.05 | |
| 5 | VP 1 × ANDCI 10-5 | 8.03 | | -26.00 | ** | -22.11 | ** | 92.79 | ** | -37.38 | ** | -17.32 | ** |
| 6 | VP 1 × ANDCI 12-2 | 2.55 | | -29.75 | ** | -26.05 | ** | 81.41 | ** | -41.07 | ** | -22.20 | ** |
| 7 | VP 1 × 48-1 | 4.38 | | -28.50 | ** | -24.74 | ** | 96.51 | ** | -36.17 | ** | -15.72 | ** |
| 8 | VP 1 × DCS 97 | 9.12 | * | -25.25 | ** | -21.32 | ** | 152.30 | ** | -18.05 | ** | 8.21 | |
| 9 | VP 1 × SKI 215 | 16.79 | ** | -20.00 | ** | -15.79 | ** | 134.16 | ** | -23.94 | ** | 0.43 | |
| 10 | VP 1 × GP 640 | 10.22 | * | -24.50 | ** | -20.53 | ** | 127.67 | ** | -26.05 | ** | -2.36 | |
| 11 | VP 1 × SKI 315 | 16.79 | ** | -20.00 | ** | -15.79 | ** | 97.32 | ** | -35.90 | ** | -15.37 | ** |
| 12 | VP 1 × SKI 343 | 16.06 | ** | -20.50 | ** | -16.32 | ** | 103.70 | ** | -33.83 | ** | -12.64 | * |
| 13 | VP 1 × RB 1 | 9.49 | * | -25.00 | ** | -21.05 | ** | 109.83 | ** | -31.84 | ** | -10.01 | |
| 14 | VP 1 × DCS 109 | -0.73 | | -32.00 | ** | -28.42 | ** | 137.32 | ** | -22.91 | ** | 1.78 | |
| 15 | SKP 84 × ANDCI 1 | 15.46 | ** | -8.50 | ** | -3.69 | | 1.85 | | -26.86 | ** | -3.43 | |
| 16 | SKP 84 × ANDCI 8 | 5.18 | | -18.75 | ** | -14.48 | ** | 24.32 | ** | -10.72 | ** | 17.87 | ** |
| 17 | SKP 84 × ANDCI 14 | 15.14 | ** | -8.75 | ** | -3.95 | | 46.17 | ** | 4.96 | | 38.58 | ** |
| 18 | SKP 84 × ANDCI 10-3 | 14.51 | ** | -9.25 | ** | -4.48 | | 17.36 | ** | -15.72 | ** | 11.28 | * |
| 19 | SKP 84 × ANDCI 10-5 | 4.84 | | -24.25 | ** | -20.27 | ** | 45.50 | ** | 4.49 | | 37.96 | ** |
| 20 | SKP 84 × ANDCI 12-2 | 12.62 | ** | -10.75 | ** | -6.06 | | 40.17 | ** | 0.66 | | 32.90 | ** |
| 21 | SKP 84 × 48-1 | -2.84 | | -23.00 | ** | -18.95 | ** | 20.13 | ** | -13.74 | ** | 13.89 | ** |
| 22 | SKP 84 × DCS 97 | -9.15 | * | -28.00 | ** | -24.21 | ** | 33.43 | ** | -4.19 | | 26.50 | ** |
| 23 | SKP 84 × SKI 215 | 10.41 | ** | -12.50 | ** | -7.90 | * | 39.73 | ** | 0.34 | | 32.48 | ** |
| 24 | SKP 84 × GP 640 | -1.26 | | -21.75 | ** | -17.63 | ** | 32.14 | ** | -5.11 | | 25.29 | ** |
| 25 | SKP 84 × SKI 315 | 9.78 | * | -13.00 | ** | -8.42 | * | -4.79 | | -31.63 | ** | -9.73 | |
| 26 | SKP 84 × SKI 343 | 2.84 | | -18.50 | ** | -14.21 | ** | 0.41 | | -27.89 | ** | -4.80 | |
| 27 | SKP 84 × RB 1 | -15.14 | ** | -32.75 | ** | -29.21 | ** | -14.87 | ** | -38.87 | ** | -19.29 | ** |
| 28 | SKP 84 × DCS 109 | -9.30 | * | -31.75 | ** | -28.16 | ** | 21.08 | ** | -20.11 | ** | 5.48 | |
| 29 | Geeta × ANDCI 1 | -7.55 | * | -14.25 | ** | -9.74 | ** | -31.20 | ** | -13.57 | ** | 14.12 | ** |
| 30 | Geeta × ANDCI 8 | 16.50 | ** | -10.00 | ** | -5.27 | | 27.54 | ** | 14.55 | ** | 51.24 | ** |
| 31 | Geeta × ANDCI 14 | -15.43 | ** | -23.25 | ** | -19.21 | ** | 21.32 | ** | 9.98 | * | 45.21 | ** |
| 32 | Geeta × ANDCI 10-3 | 6.63 | | -7.50 | * | -2.63 | | -0.50 | | -1.70 | | 29.79 | ** |
| 33 | Geeta × ANDCI 10-5 | 32.18 | ** | -4.50 | | 0.52 | | -20.23 | ** | -5.84 | | 24.32 | ** |
| 34 | Geeta × ANDCI 12-2 | -5.60 | | -20.00 | ** | -15.79 | ** | -10.97 | ** | 1.35 | | 33.82 | ** |
| 35 | Geeta × 48-1 | 2.33 | | -12.25 | ** | -7.63 | * | 16.33 | ** | 7.06 | | 41.36 | ** |
| 36 | Geeta × DCS 97 | 2.43 | | -15.75 | ** | -11.32 | ** | 0.80 | | 1.15 | | 33.55 | ** |
| 37 | Geeta × SKI 215 | -0.27 | | -9.25 | ** | -4.48 | | -2.54 | | 4.46 | | 37.92 | ** |
| 38 | Geeta × GP 640 | 6.74 | | -9.00 | ** | -4.21 | | 29.63 | ** | 4.85 | | 38.43 | ** |
| 39 | Geeta × SKI 315 | -10.65 | ** | -24.50 | ** | -20.53 | ** | 16.80 | ** | -4.19 | | 26.50 | ** |
| 40 | Geeta × SKI 343 | -2.52 | | -22.75 | ** | -18.69 | ** | 25.56 | ** | 9.68 | * | 44.81 | ** |
| 41 | Geeta × RB 1 | -13.48 | ** | -19.75 | ** | -15.53 | ** | 10.05 | * | -6.37 | | 23.62 | ** |
| 42 | Geeta × DCS 109 | 1.99 | | -23.25 | ** | -19.21 | ** | 55.17 | ** | 2.38 | | 35.18 | ** |
| Range | Min. | -15.43 | | -37.50 | | -34.21 | | -31.20 | | -41.07 | | -22.20 | |
| | Max. | 32.18 | | -4.50 | | 0.52 | | 152.30 | | 14.55 | | 51.24 | |
| S. E.± | | 4.20 | | | | | | 2.71 | | | | | |
| No of significant crosses | | 23 | | 41 | | 33 | | 36 | | 26 | | 29 | |
| Positive | | 16 | | 0 | | 0 | | 32 | | 3 | | 23 | |
| Negative | | 7 | | 41 | | 33 | | 4 | | 23 | | 6 | |

*, **, Significant at 5% and 1% levels of significance, respectively. BP = Better parent, $SC_1$ = Standard heterosis over check hybrid GCH 7 and $SC_2$ = Standard heterosis over check hybrid GNCH 1.

**Table 2.3:** Estimates of heterobeltiosis and standard heterosis for total length of primary raceme and effective length of primary raceme

| Sr. No. | Hybrids | Total length of primary raceme | | | | | | Effective length of primary raceme | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Heterosis over | | | | | | Heterosis over | | | | | |
| | | BP | | $SC_1$ | | $SC_2$ | | BP | | $SC_1$ | | $SC_2$ | |
| 1 | VP 1 × ANDCI 1 | -7.11 | | -20.09 | ** | -17.83 | ** | -15.52 | ** | -20.45 | ** | -23.25 | ** |
| 2 | VP 1 × ANDCI 8 | -4.32 | | 1.99 | | 4.87 | | -1.60 | | 9.19 | * | 5.35 | |
| 3 | VP 1 × ANDCI 14 | 35.67 | ** | 6.73 | | 9.74 | * | 43.81 | ** | 17.30 | ** | 13.18 | ** |
| 4 | VP 1 × ANDCI 10-3 | -2.09 | | -10.69 | ** | -8.18 | | -12.54 | ** | -13.55 | ** | -16.59 | ** |
| 5 | VP 1 × ANDCI 10-5 | -22.55 | ** | -24.06 | ** | -21.92 | ** | -25.53 | ** | -23.29 | ** | -25.99 | ** |
| 6 | VP 1 × ANDCI 12-2 | -31.79 | ** | -21.07 | ** | -18.84 | ** | -34.10 | ** | -17.09 | ** | -20.01 | ** |
| 7 | VP 1 × 48-1 | 11.60 | * | -0.13 | | 2.68 | | 1.38 | | -2.73 | | -6.15 | |
| 8 | VP 1 × DCS 97 | -16.92 | ** | -10.07 | * | -7.54 | | -14.56 | ** | -7.07 | | -10.34 | * |
| 9 | VP 1 × SKI 215 | -19.92 | ** | -14.18 | ** | -11.76 | ** | -12.46 | ** | -5.95 | | -9.26 | * |
| 10 | VP 1 × GP 640 | 16.34 | ** | -3.24 | | -0.51 | | 17.69 | ** | -8.36 | | -11.58 | ** |
| 11 | VP 1 × SKI 315 | 17.43 | ** | -9.45 | * | -6.90 | | 13.78 | * | -8.83 | | -12.03 | ** |
| 12 | VP 1 × SKI 343 | -7.98 | * | 3.30 | | 6.21 | | -12.03 | ** | 5.78 | | 2.06 | |
| 13 | VP 1 × RB 1 | 5.34 | | -9.83 | * | -7.28 | | 2.79 | | -7.08 | | -10.34 | * |
| 14 | VP 1 × DCS 109 | 33.84 | ** | -3.67 | | -0.96 | | 39.56 | ** | 2.32 | | -1.28 | |
| 15 | SKP 84 × ANDCI 1 | -27.41 | ** | -19.28 | ** | -17.01 | ** | -29.46 | ** | -12.20 | ** | -15.28 | ** |
| 16 | SKP 84 × ANDCI 8 | -5.26 | | 5.35 | | 8.32 | * | -13.70 | ** | 7.42 | | 3.64 | |
| 17 | SKP 84 × ANDCI 14 | 2.47 | | 13.94 | ** | 17.15 | ** | 2.75 | | 27.88 | ** | 23.39 | ** |
| 18 | SKP 84 × ANDCI 10-3 | -19.46 | ** | -10.45 | * | -7.92 | | -22.83 | ** | -3.95 | | -7.33 | |
| 19 | SKP 84 × ANDCI 10-5 | -6.82 | | 3.61 | | 6.53 | | -14.50 | ** | 6.42 | | 2.68 | |
| 20 | SKP 84 × ANDCI 12-2 | -0.36 | | 15.29 | ** | 18.55 | ** | -2.88 | | 22.19 | ** | 17.89 | ** |
| 21 | SKP 84 × 48-1 | -14.04 | ** | -4.42 | | -1.72 | | -18.97 | ** | 0.85 | | -2.69 | |
| 22 | SKP 84 × DCS 97 | -15.38 | ** | -5.91 | | -3.25 | | -27.72 | ** | -10.04 | * | -13.20 | ** |
| 23 | SKP 84 × SKI 215 | -8.17 | * | 2.11 | | 4.99 | | -11.99 | ** | 9.55 | * | 5.70 | |
| 24 | SKP 84 × GP 640 | -2.97 | | 7.89 | | 10.94 | ** | -7.81 | * | 14.74 | ** | 10.71 | * |
| 25 | SKP 84 × SKI 315 | -22.68 | ** | -14.03 | ** | -11.60 | ** | -33.61 | ** | -17.37 | ** | -20.27 | ** |
| 26 | SKP 84 × SKI 343 | -20.78 | ** | -11.07 | ** | -8.57 | * | -31.17 | ** | -14.33 | ** | -17.34 | ** |
| 27 | SKP 84 × RB 1 | -19.72 | ** | -10.74 | ** | -8.22 | | -22.74 | ** | -3.83 | | -7.22 | |
| 28 | SKP 84 × DCS 109 | -8.00 | * | 2.30 | | 5.19 | | -12.90 | ** | 8.41 | | 4.60 | |
| 29 | Geeta × ANDCI 1 | -25.55 | ** | -18.63 | ** | -16.33 | ** | -28.00 | ** | -16.13 | ** | -19.08 | ** |
| 30 | Geeta × ANDCI 8 | -9.70 | ** | -1.30 | | 1.48 | | -13.21 | ** | 1.10 | | -2.46 | |
| 31 | Geeta × ANDCI 14 | 4.23 | | 13.93 | ** | 17.14 | ** | -0.67 | | 15.70 | ** | 11.63 | ** |
| 32 | Geeta × ANDCI 10-3 | -18.73 | ** | -11.17 | ** | -8.66 | * | -20.69 | ** | -7.62 | | -10.86 | * |
| 33 | Geeta × ANDCI 10-5 | -15.67 | ** | -7.82 | | -5.22 | | -16.30 | ** | -2.51 | | -5.94 | |
| 34 | Geeta × ANDCI 12-2 | -11.27 | ** | 2.67 | | 5.57 | | -11.14 | ** | 11.80 | ** | 7.86 | |
| 35 | Geeta × 48-1 | -31.61 | ** | -25.25 | ** | -23.14 | ** | -30.84 | ** | -19.44 | ** | -22.27 | ** |
| 36 | Geeta × DCS 97 | -13.75 | ** | -5.72 | | -3.06 | | -15.65 | ** | -1.75 | | -5.20 | |
| 37 | Geeta × SKI 215 | -25.54 | ** | -18.62 | ** | -16.32 | ** | -27.79 | ** | -15.89 | ** | -18.84 | ** |
| 38 | Geeta × GP 640 | -26.89 | ** | -20.09 | ** | -17.83 | ** | -27.27 | ** | -15.28 | ** | -18.26 | ** |
| 39 | Geeta × SKI 315 | -19.44 | ** | -11.94 | ** | -9.46 | * | -16.20 | ** | -2.39 | | -5.82 | |
| 40 | Geeta × SKI 343 | -3.49 | | 8.33 | * | 11.39 | ** | -2.25 | | 17.54 | ** | 13.40 | ** |
| 41 | Geeta × RB 1 | -20.54 | ** | -13.14 | ** | -10.69 | * | -20.06 | ** | -6.89 | | -10.16 | * |
| 42 | Geeta × DCS 109 | -14.09 | ** | -6.09 | | -3.45 | | -13.52 | ** | 0.74 | | -2.80 | |
| Range | Min. | -31.79 | | -25.25 | | -23.14 | | -34.10 | | -23.29 | | -25.99 | |
| | Max. | 35.67 | | 15.29 | | 18.55 | | 43.81 | | 27.88 | | 23.39 | |
| S. E.± | | 2.19 | | | | | | 2.12 | | | | | |
| No of significant crosses | | 31 | | 24 | | 21 | | 35 | | 21 | | 25 | |
| Positive | | 5 | | 4 | | 7 | | 4 | | 9 | | 6 | |
| Negative | | 26 | | 20 | | 14 | | 31 | | 12 | | 19 | |

*, **, Significant at 5% and 1% levels of significance, respectively. BP = Better parent, $SC_1$ = Standard heterosis over check hybrid GCH 7 and $SC_2$ = Standard heterosis over check hybrid GNCH 1.

**Table 2.4:** Estimates of heterobeltiosis and standard heterosis for number of capsules on primary raceme and effective number of spikes per plant

| Sr. No. | Hybrids | Number of capsules on primary raceme | | | | | | Effective number of spikes per plant | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Heterosis over | | | | | | Heterosis over | | | | | |
| | | BP | | $SC_1$ | | $SC_2$ | | BP | | $SC_1$ | | $SC_2$ | |
| 1 | VP 1 × ANDCI 1 | 7.03 | | -20.30 | ** | -17.04 | ** | -25.09 | ** | -36.11 | ** | -34.54 | ** |
| 2 | VP 1 × ANDCI 8 | -26.37 | ** | -28.63 | ** | -25.71 | ** | -41.67 | ** | -42.30 | ** | -40.87 | ** |
| 3 | VP 1 × ANDCI 14 | -36.04 | ** | -54.19 | ** | -52.32 | ** | -58.77 | ** | -61.43 | ** | -60.48 | ** |
| 4 | VP 1 × ANDCI 10-3 | -25.38 | ** | -27.05 | ** | -24.07 | ** | -54.71 | ** | -54.01 | ** | -52.88 | ** |
| 5 | VP 1 × ANDCI 10-5 | -43.38 | ** | -45.56 | ** | -43.33 | ** | -56.60 | ** | -59.27 | ** | -58.27 | ** |
| 6 | VP 1 × ANDCI 12-2 | -3.00 | | -5.10 | | -1.21 | | -40.47 | ** | -45.27 | ** | -43.92 | ** |
| 7 | VP 1 × 48-1 | -18.70 | ** | -19.67 | ** | -16.38 | ** | -52.98 | ** | -53.68 | ** | -52.54 | ** |
| 8 | VP 1 × DCS 97 | -16.14 | ** | -16.88 | ** | -13.48 | * | -24.01 | ** | -27.67 | ** | -25.89 | ** |
| 9 | VP 1 × SKI 215 | -27.98 | ** | -27.40 | ** | -24.43 | ** | -42.59 | ** | -42.49 | ** | -41.08 | ** |
| 10 | VP 1 × GP 640 | -16.94 | ** | -17.23 | ** | -13.84 | ** | -41.34 | ** | -44.36 | ** | -42.99 | ** |
| 11 | VP 1 × SKI 315 | -36.36 | ** | -40.69 | ** | -38.27 | ** | -49.74 | ** | -59.96 | ** | -58.97 | ** |
| 12 | VP 1 × SKI 343 | -13.04 | * | -27.83 | ** | -24.88 | ** | -44.63 | ** | -60.55 | ** | -59.58 | ** |
| 13 | VP 1 × RB 1 | -46.15 | ** | -47.72 | ** | -45.58 | ** | -22.01 | * | -40.53 | ** | -39.06 | ** |
| 14 | VP 1 × DCS 109 | 57.87 | ** | -4.62 | | -0.72 | | -8.38 | | -47.40 | ** | -46.10 | ** |
| 15 | SKP 84 × ANDCI 1 | -5.91 | | -12.86 | * | -9.30 | | 7.24 | | -8.54 | | -6.28 | |
| 16 | SKP 84 × ANDCI 8 | 4.62 | | 1.41 | | 5.56 | | -22.02 | ** | -22.87 | ** | -20.97 | ** |
| 17 | SKP 84 × ANDCI 14 | -2.63 | | -9.82 | | -6.13 | | 43.62 | ** | 34.35 | ** | 37.66 | ** |
| 18 | SKP 84 × ANDCI 10-3 | -15.77 | ** | -17.65 | ** | -14.29 | ** | -8.34 | | -6.94 | | -4.65 | |
| 19 | SKP 84 × ANDCI 10-5 | -13.69 | * | -17.01 | ** | -13.62 | * | -4.34 | | -10.24 | | -8.02 | |
| 20 | SKP 84 × ANDCI 12-2 | -2.40 | | -4.51 | | -0.60 | | -2.66 | | -10.50 | | -8.30 | |
| 21 | SKP 84 × 48-1 | -19.31 | ** | -20.27 | ** | -17.00 | ** | -10.34 | | -11.68 | | -9.50 | |
| 22 | SKP 84 × DCS 97 | -31.30 | ** | -31.91 | ** | -29.12 | ** | -31.23 | ** | -34.54 | ** | -32.93 | ** |
| 23 | SKP 84 × SKI 215 | -17.34 | ** | -16.68 | ** | -13.27 | * | -3.30 | | -3.14 | | -0.75 | |
| 24 | SKP 84 × GP 640 | -29.49 | ** | -29.74 | ** | -26.86 | ** | -3.79 | | -8.73 | | -6.49 | |
| 25 | SKP 84 × SKI 315 | -28.08 | ** | -32.97 | ** | -30.23 | ** | -21.90 | ** | -37.78 | ** | -36.25 | ** |
| 26 | SKP 84 × SKI 343 | -12.31 | * | -18.78 | ** | -15.46 | ** | 19.31 | * | -9.03 | | -6.79 | |
| 27 | SKP 84 × RB 1 | -19.68 | ** | -22.01 | ** | -18.82 | ** | 15.19 | | -12.17 | | -10.01 | |
| 28 | SKP 84 × DCS 109 | -33.33 | ** | -38.26 | ** | -35.73 | ** | -18.15 | * | -37.59 | ** | -36.05 | ** |
| 29 | Geeta × ANDCI 1 | 3.22 | | -0.08 | | 4.00 | | 14.48 | * | 3.34 | | 5.88 | |
| 30 | Geeta × ANDCI 8 | -4.22 | | -7.16 | | -3.37 | | -5.06 | | -6.08 | | -3.77 | |
| 31 | Geeta × ANDCI 14 | 3.62 | | 0.30 | | 4.41 | | 12.57 | | 5.30 | | 7.89 | |
| 32 | Geeta × ANDCI 10-3 | -12.65 | * | -14.61 | ** | -11.11 | * | -21.42 | ** | -20.22 | ** | -18.25 | ** |
| 33 | Geeta × ANDCI 10-5 | 3.91 | | 0.58 | | 4.70 | | 17.86 | * | 10.60 | | 13.32 | * |
| 34 | Geeta × ANDCI 12-2 | -2.22 | | -4.33 | | -0.42 | | 48.04 | ** | 36.11 | ** | 39.47 | ** |
| 35 | Geeta × 48-1 | 3.67 | | 2.44 | | 6.63 | | 25.82 | ** | 23.95 | ** | 27.00 | ** |
| 36 | Geeta × DCS 97 | 3.73 | | 2.82 | | 7.03 | | 37.01 | ** | 30.41 | ** | 33.62 | ** |
| 37 | Geeta × SKI 215 | 4.52 | | 5.36 | | 9.67 | | 37.22 | ** | 37.45 | ** | 40.83 | ** |
| 38 | Geeta × GP 640 | 3.40 | | 3.04 | | 7.25 | | 37.38 | ** | 30.31 | ** | 33.52 | ** |
| 39 | Geeta × SKI 315 | 8.44 | | 4.96 | | 9.26 | | 48.73 | ** | 34.25 | ** | 37.56 | ** |
| 40 | Geeta × SKI 343 | 9.26 | | 5.76 | | 10.09 | | 64.71 | ** | 48.68 | ** | 52.34 | ** |
| 41 | Geeta × RB 1 | 3.94 | | 0.91 | | 5.04 | | 18.30 | * | 6.79 | | 9.42 | |
| 42 | Geeta × DCS 109 | 1.71 | | -1.54 | | 2.48 | | 12.09 | | 1.18 | | 3.67 | |
| Range | Min. | -46.15 | | -54.19 | | -52.32 | | -58.77 | | -61.43 | | -60.48 | |
| | Max. | 57.87 | | 5.76 | | 10.09 | | 64.71 | | 48.68 | | 52.34 | |
| S. E.± | | 5.12 | | | | | | 0.73 | | | | | |
| No of significant crosses | | 23 | | 24 | | 23 | | 30 | | 27 | | 28 | |
| Positive | | 1 | | 0 | | 0 | | 12 | | 8 | | 9 | |
| Negative | | 22 | | 24 | | 23 | | 18 | | 19 | | 19 | |

*, **, Significant at 5% and 1% levels of significance, respectively. BP = Better parent, $SC_1$ = Standard heterosis over check hybrid GCH 7 and $SC_2$ = Standard heterosis over check hybrid GNCH 1.

**Table 2.5:** Estimates of heterobeltiosis and standard heterosis for seed yield per plant and shelling out-turn

| Sr. No. | Hybrids | Seed yield per plant | | | | | | Shelling out-turn | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Heterosis over | | | | | | Heterosis over | | | | | |
| | | BP | | $SC_1$ | | $SC_2$ | | BP | | $SC_1$ | | $SC_2$ | |
| 1 | VP 1 × ANDCI 1 | 0.43 | | -21.13 | * | -19.60 | | -3.06 | | -12.63 | | -12.19 | |
| 2 | VP 1 × ANDCI 8 | -20.21 | | -23.13 | * | -21.64 | * | 5.41 | | -13.36 | | -12.92 | |
| 3 | VP 1 × ANDCI 14 | -40.51 | ** | -44.99 | ** | -43.92 | ** | 5.95 | | -12.57 | | -12.13 | |
| 4 | VP 1 × ANDCI 10-3 | -52.95 | ** | -54.47 | ** | -53.59 | ** | 3.54 | | -14.49 | * | -14.05 | * |
| 5 | VP 1 × ANDCI 10-5 | -52.92 | ** | -55.58 | ** | -54.72 | ** | -2.15 | | -18.54 | ** | -18.13 | * |
| 6 | VP 1 × ANDCI 12-2 | -23.62 | * | -26.52 | ** | -25.10 | * | -5.92 | | -16.52 | * | -16.10 | * |
| 7 | VP 1 × 48-1 | -28.10 | ** | -30.11 | ** | -28.76 | ** | -16.95 | * | -24.46 | ** | -24.08 | ** |
| 8 | VP 1 × DCS 97 | -6.33 | | -10.34 | | -8.61 | | 4.48 | | -15.82 | * | -15.40 | * |
| 9 | VP 1 × SKI 215 | -22.42 | * | -23.31 | * | -21.83 | * | 8.21 | | -1.61 | | -1.11 | |
| 10 | VP 1 × GP 640 | -20.47 | | -23.75 | * | -22.27 | * | -1.36 | | -5.67 | | -5.19 | |
| 11 | VP 1 × SKI 315 | -25.60 | * | -27.91 | ** | -26.52 | ** | 0.74 | | -2.69 | | -2.19 | |
| 12 | VP 1 × SKI 343 | -29.51 | ** | -32.79 | ** | -31.49 | ** | -4.52 | | -16.49 | * | -16.07 | * |
| 13 | VP 1 × RB 1 | -21.03 | * | -23.49 | * | -22.01 | * | -5.60 | | -8.36 | | -7.90 | |
| 14 | VP 1 × DCS 109 | 1.54 | | -25.57 | * | -24.13 | * | -11.98 | | -18.89 | ** | -18.48 | ** |
| 15 | SKP 84 × ANDCI 1 | 30.57 | * | 9.11 | | 11.22 | | 9.64 | | -1.19 | | -0.69 | |
| 16 | SKP 84 × ANDCI 8 | -5.19 | | -8.66 | | -6.89 | | 16.26 | * | -0.51 | | -0.01 | |
| 17 | SKP 84 × ANDCI 14 | 55.35 | ** | 43.66 | ** | 46.44 | ** | 7.17 | | -8.29 | | -7.82 | |
| 18 | SKP 84 × ANDCI 10-3 | 26.18 | * | 22.08 | * | 24.45 | * | 15.46 | | -1.20 | | -0.70 | |
| 19 | SKP 84 × ANDCI 10-5 | 10.10 | | 3.88 | | 5.89 | | 9.69 | | -6.13 | | -5.66 | |
| 20 | SKP 84 × ANDCI 12-2 | 3.51 | | -0.43 | | 1.50 | | 12.19 | | -0.44 | | 0.06 | |
| 21 | SKP 84 × 48-1 | 15.72 | | 12.48 | | 14.66 | | 10.64 | | 0.65 | | 1.16 | |
| 22 | SKP 84 × DCS 97 | -13.27 | | -16.98 | | -15.38 | | 18.67 | * | 1.55 | | 2.07 | |
| 23 | SKP 84 × SKI 215 | 2.64 | | 1.46 | | 3.43 | | 11.30 | | 1.20 | | 1.72 | |
| 24 | SKP 84 × GP 640 | 3.17 | | -1.08 | | 0.84 | | 1.63 | | -2.81 | | -2.31 | |
| 25 | SKP 84 × SKI 315 | -16.59 | | -19.18 | | -17.62 | | 7.69 | | 4.02 | | 4.55 | |
| 26 | SKP 84 × SKI 343 | 12.70 | | 7.45 | | 9.53 | | 20.13 | * | 5.06 | | 5.60 | |
| 27 | SKP 84 × RB 1 | -1.13 | | -4.21 | | -2.35 | | -1.70 | | -4.57 | | -4.09 | |
| 28 | SKP 84 × DCS 109 | -2.93 | | -18.88 | | -17.31 | | -10.23 | | -17.27 | * | -16.85 | * |
| 29 | Geeta × ANDCI 1 | 44.51 | ** | 36.21 | ** | 38.85 | ** | 13.33 | | 2.14 | | 2.66 | |
| 30 | Geeta × ANDCI 8 | 4.78 | | 0.94 | | 2.90 | | 9.05 | | -8.16 | | -7.69 | |
| 31 | Geeta × ANDCI 14 | 23.78 | * | 16.68 | | 18.94 | | 12.46 | | -5.29 | | -4.81 | |
| 32 | Geeta × ANDCI 10-3 | -10.07 | | -12.99 | | -11.30 | | 12.09 | | -5.60 | | -5.13 | |
| 33 | Geeta × ANDCI 10-5 | 25.84 | * | 18.73 | | 21.03 | * | 18.87 | * | 0.11 | | 0.61 | |
| 34 | Geeta × ANDCI 12-2 | 57.01 | ** | 51.03 | ** | 53.96 | ** | 10.63 | | -1.83 | | -1.33 | |
| 35 | Geeta × 48-1 | 25.11 | * | 21.61 | * | 23.96 | * | -34.32 | ** | -40.26 | ** | -39.96 | ** |
| 36 | Geeta × DCS 97 | 24.67 | * | 19.33 | | 21.64 | * | 18.43 | * | -0.26 | | 0.25 | |
| 37 | Geeta × SKI 215 | 48.54 | ** | 46.83 | ** | 49.67 | ** | 10.33 | | 0.32 | | 0.83 | |
| 38 | Geeta × GP 640 | 17.39 | | 12.55 | | 14.73 | | -5.00 | | -9.15 | | -8.69 | |
| 39 | Geeta × SKI 315 | 76.37 | ** | 70.89 | ** | 74.20 | ** | 4.77 | | 1.20 | | 1.71 | |
| 40 | Geeta × SKI 343 | 78.91 | ** | 70.58 | ** | 73.88 | ** | 13.66 | | -0.60 | | -0.09 | |
| 41 | Geeta × RB 1 | 38.23 | ** | 33.92 | ** | 36.52 | ** | 2.47 | | -0.52 | | -0.01 | |
| 42 | Geeta × DCS 109 | 18.62 | | 11.81 | | 13.97 | | 2.52 | | -5.53 | | -5.05 | |
| Range | Min. | -52.95 | | -55.58 | | -54.72 | | -34.32 | | -40.26 | | -39.96 | |
| | Max. | 78.91 | | 70.89 | | 74.20 | | 20.13 | | 5.06 | | 5.60 | |
| S. E.± | | 21.94 | | | | | | 5.02 | | | | | |
| No of significant crosses | | 22 | | 22 | | 23 | | 7 | | 9 | | 9 | |
| Positive | | 13 | | 9 | | 11 | | 5 | | 0 | | 0 | |
| Negative | | 9 | | 13 | | 12 | | 2 | | 9 | | 9 | |

*, **, Significant at 5% and 1% levels of significance, respectively. BP = Better parent, $SC_1$ = Standard heterosis over check hybrid GCH 7 and $SC_2$ = Standard heterosis over check hybrid GNCH 1.

**Table 2.6:** Estimates of heterobeltiosis and standard heterosis for 100 seed weight and oil content

| Sr. No. | Hybrids | 100 Seed weight | | | | | | Oil content | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Heterosis over | | | | | | Heterosis over | | | | | |
| | | BP | | $SC_1$ | | $SC_2$ | | BP | | $SC_1$ | | $SC_2$ | |
| 1 | VP 1 × ANDCI 1 | 3.92 | | -21.84 | ** | -13.65 | ** | -2.73 | | -2.78 | | 0.48 | |
| 2 | VP 1 × ANDCI 8 | -12.67 | ** | -17.54 | ** | -8.90 | * | 1.17 | | -2.57 | | 0.70 | |
| 3 | VP 1 × ANDCI 14 | -31.40 | ** | -33.04 | ** | -26.03 | ** | -0.61 | | -3.11 | | 0.15 | |
| 4 | VP 1 × ANDCI 10-3 | -10.46 | ** | -16.80 | ** | -8.08 | * | -1.84 | | -1.70 | | 1.59 | |
| 5 | VP 1 × ANDCI 10-5 | -21.30 | ** | -31.13 | ** | -23.91 | ** | 1.64 | | -0.28 | | 3.07 | |
| 6 | VP 1 × ANDCI 12-2 | 0.57 | | -8.51 | * | 1.08 | | -1.48 | | -5.62 | ** | -2.45 | |
| 7 | VP 1 × 48-1 | -16.55 | ** | -20.51 | ** | -12.18 | ** | -3.41 | | -0.29 | | 3.06 | |
| 8 | VP 1 × DCS 97 | -9.44 | * | -15.08 | ** | -6.18 | | -0.59 | | 0.13 | | 3.49 | |
| 9 | VP 1 × SKI 215 | -12.35 | ** | -12.92 | ** | -3.80 | | 4.11 | * | 1.47 | | 4.88 | * |
| 10 | VP 1 × GP 640 | -12.57 | ** | -14.12 | ** | -5.12 | | -4.83 | ** | -1.16 | | 2.16 | |
| 11 | VP 1 × SKI 315 | -28.31 | ** | -25.69 | ** | -17.90 | ** | 0.80 | | -1.27 | | 2.05 | |
| 12 | VP 1 × SKI 343 | -6.49 | | -19.35 | ** | -10.90 | ** | 0.90 | | -0.85 | | 2.48 | |
| 13 | VP 1 × RB 1 | -21.07 | ** | -23.36 | ** | -15.33 | ** | -4.02 | * | 1.23 | | 4.63 | * |
| 14 | VP 1 × DCS 109 | 34.07 | ** | -5.91 | | 3.94 | | 0.32 | | -3.70 | | -0.47 | |
| 15 | SKP 84 × ANDCI 1 | 4.69 | | -0.78 | | 9.61 | * | -3.25 | | -2.47 | | 0.80 | |
| 16 | SKP 84 × ANDCI 8 | 10.67 | ** | 4.88 | | 15.87 | ** | -5.11 | ** | -4.35 | * | -1.14 | |
| 17 | SKP 84 × ANDCI 14 | 5.57 | | 3.04 | | 13.83 | ** | -2.53 | | -1.76 | | 1.54 | |
| 18 | SKP 84 × ANDCI 10-3 | 4.25 | | -1.20 | | 9.15 | * | -1.09 | | -0.30 | | 3.04 | |
| 19 | SKP 84 × ANDCI 10-5 | -11.12 | ** | -15.76 | ** | -6.94 | | -1.94 | | -1.16 | | 2.16 | |
| 20 | SKP 84 × ANDCI 12-2 | -3.75 | | -8.78 | * | 0.78 | | -4.26 | * | -3.49 | | -0.25 | |
| 21 | SKP 84 × 48-1 | -8.26 | * | -12.62 | ** | -3.46 | | -2.18 | | 0.99 | | 4.38 | * |
| 22 | SKP 84 × DCS 97 | -17.04 | ** | -21.38 | ** | -13.14 | ** | -0.54 | | 0.26 | | 3.62 | |
| 23 | SKP 84 × SKI 215 | -11.22 | ** | -11.80 | ** | -2.55 | | -0.45 | | 0.34 | | 3.71 | |
| 24 | SKP 84 × GP 640 | -21.50 | ** | -22.89 | ** | -14.81 | ** | -3.42 | | 0.31 | | 3.68 | |
| 25 | SKP 84 × SKI 315 | -22.21 | ** | -19.37 | ** | -10.93 | ** | -3.17 | | -2.40 | | 0.88 | |
| 26 | SKP 84 × SKI 343 | -5.90 | | -10.82 | ** | -1.48 | | -1.31 | | -0.53 | | 2.81 | |
| 27 | SKP 84 × RB 1 | 1.00 | | -1.93 | | 8.34 | * | -1.19 | | 4.22 | * | 7.71 | ** |
| 28 | SKP 84 × DCS 109 | -11.95 | ** | -16.55 | ** | -7.81 | * | -2.48 | | -1.70 | | 1.60 | |
| 29 | Geeta × ANDCI 1 | 12.75 | ** | -2.38 | | 7.84 | * | -0.95 | | -1.00 | | 2.32 | |
| 30 | Geeta × ANDCI 8 | 2.47 | | -3.24 | | 6.90 | | 5.87 | ** | 2.33 | | 5.76 | ** |
| 31 | Geeta × ANDCI 14 | -3.54 | | -5.86 | | 4.01 | | 6.80 | ** | 4.12 | * | 7.61 | ** |
| 32 | Geeta × ANDCI 10-3 | 2.69 | | -4.58 | | 5.42 | | 2.16 | | 2.30 | | 5.74 | ** |
| 33 | Geeta × ANDCI 10-5 | 18.26 | ** | 3.50 | | 14.34 | ** | 6.35 | ** | 4.35 | * | 7.85 | ** |
| 34 | Geeta × ANDCI 12-2 | 19.33 | ** | 8.56 | * | 19.93 | ** | 5.51 | ** | 1.98 | | 5.41 | ** |
| 35 | Geeta × 48-1 | 13.26 | ** | 7.88 | * | 19.18 | ** | 0.84 | | 4.10 | * | 7.60 | ** |
| 36 | Geeta × DCS 97 | 20.37 | ** | 12.87 | ** | 24.70 | ** | 2.79 | | 3.53 | | 7.00 | ** |
| 37 | Geeta × SKI 215 | 16.62 | ** | 15.86 | ** | 28.00 | ** | 3.60 | | 0.97 | | 4.36 | * |
| 38 | Geeta × GP 640 | 11.18 | ** | 9.21 | ** | 20.66 | ** | 1.77 | | 5.69 | ** | 9.24 | ** |
| 39 | Geeta × SKI 315 | 8.29 | * | 12.25 | ** | 24.01 | ** | 1.65 | | -0.44 | | 2.90 | |
| 40 | Geeta × SKI 343 | 39.29 | ** | 20.59 | ** | 33.23 | ** | 4.31 | * | 2.51 | | 5.95 | ** |
| 41 | Geeta × RB 1 | 13.27 | ** | 9.98 | ** | 21.50 | ** | -0.60 | | 4.83 | * | 8.35 | ** |
| 42 | Geeta × DCS 109 | 11.56 | ** | -3.41 | | 6.71 | | 3.37 | | -0.09 | | 3.26 | |
| Range | Min. | -31.40 | | -33.04 | | -26.03 | | -5.11 | | -5.62 | | -2.45 | |
| | Max. | 39.29 | | 20.59 | | 33.23 | | 6.80 | | 5.69 | | 9.24 | |
| S. E.$\pm$ | | | | | | | | | | | | | |
| No of significant crosses | | 30 | | 30 | | 28 | | 10 | | 8 | | 15 | |
| Positive | | 13 | | 8 | | 15 | | 6 | | 6 | | 15 | |
| Negative | | 17 | | 22 | | 13 | | 4 | | 2 | | 0 | |

*, **, Significant at 5% and 1% levels of significance, respectively. BP = Better parent, $SC_1$ = Standard heterosis over check hybrid GCH 7 and $SC_2$ = Standard heterosis over check hybrid GNCH 1.

**Table 3:** Promising hybrids for seed yield per plant with heterosis over better parent and standard check hybrid (GCH 7) with their *sca* effects and component characters showing significant desired heterobeltiosisand standard heterosis in castor

| Sr. No. | Hybrids | Seed yield per plant (g) | Heterosis over | | *sca* effects | | Significant and desirable heterosis over BP and $SC_1$ for component traits | |
|---|---|---|---|---|---|---|---|---|
| | | | BP | $SC_1$ | | | BP | $SC_1$ |
| 1 | Geeta× SKI 315 | 374.02 | 76.37** | 70.89** | 75.85** | (G × A) | NN, DM, PH, TLP, ELP, ENS and TW | ENS and TW |
| 2 | Geeta× SKI 343 | 373.33 | 78.91** | 70.58** | 59.52** | (G × A) | NN, PH, ENS, TW and OC | TLP, ENS and TW |
| 3 | Geeta×ANDCI 12-2 | 330.56 | 57.01** | 51.03** | 32.19** | (G × A) | NN, PH, TLP, ELP, ENS, TW and OC | ENS and TW |
| 4 | Geeta × SKI 215 | 321.36 | 48.54** | 46.83** | 22.33* | (G × A) | TLP, ELP, ENS and TW | ENS and TW |
| 5 | SKP 84×ANDCI 14 | 314.43 | 55.35** | 43.66** | 79.86** | (G × A) | DF, DM, PH and ENS | ENS |

Where, *, ** Significant at 5% and 1% level of significance. BP = Better Parent, $SC_1$ = Standard heterosis over check hybrid GCH 7.

| | | | | | |
|---|---|---|---|---|---|
| DF | = | Days to 50% flowering | TLP | = | Total Length of primary raceme (cm) |
| NN | = | Number of nodes upto primary raceme | ELP | = | Effective length of primary raceme (cm) |
| DM | = | Days to maturity of primary raceme | ENS | = | Effective number of spikes per plant |
| PH | = | Plant height upto primary raceme (cm) | TW | = | 100 Seed weight (g) |
| | | | OC | = | Oil content (%) |

## Conclusion

The study identified five promising hybrids, Geeta × SKI-343, Geeta × SKI 315, Geeta × ANDCI 12-2, SKP 84 × ANDCI 14, and Geeta × SKI 215, exhibiting superior heterobeltiosis, standard heterosis, and significant SCA effects for seed yield. These hybrids also displayed desirable traits such as high seed yield per plant, 100-seed weight, and effective spikes per plant. Their per se performance, combined with high heterosis, makes them suitable candidates for commercial cultivation. Future breeding strategies should focus on advancing these hybrids for the development of parental lines with enhanced productivity.

## References


1. Anonymous. Annual estimates of state-wise area, production, and yield of castor in India; 2023. Available from: https://seaofindia.com.
2. Chaudhari G, Patel BN. Heterosis and combining ability analysis for oil yield and its components in castor (*Ricinus communis* L.). Trends Biosci. 2014;7(22):3757–3760.
3. Dave PB. Genetic architecture of seed yield and its component characters over environments in castor [Doctoral thesis]. Anand Agricultural University, Anand Gujarat; 2015.
4. Kugashiya KG, Patel BN, Vekariya KJ. Study of heterosis for seed yield and its component traits in castor (*Ricinus communis* L.). Int J Curr Microbiol Appl Sci. 2017;6(8):66–74.
5. Panse VG, Sukhatme PV. Statistical methods for agricultural workers. New Delhi: ICAR; 1978.
6. Peng M, Wang Z, He Z, Li G, Di J, Luo R, Huang F. Combining ability, heritability, and heterosis for seed weight and oil content traits of castor bean (*Ricinus communis* L.). Agronomy. 2024;14(6):1115.
7. Punewar AA, Patil AS, Nandanwar HR, Patel SM, Patel BN. Genetic dissection of heterosis and combining ability in castor (*Ricinus communis* L.) with Line × Tester analysis. J Exp Biol Agric Sci. 2017;5(1):077–086.
8. Sapovadia MH. Heterosis, gene action and combining ability over environments for seed yield and its components in castor [Doctoral thesis]. Junagadh Agricultural University, Junagadh; 2015.
9. Snedecor GW, Cochran WG. Statistical methods. 6th ed. Ames: Iowa State University Press; 1967.
10. Shull GH. Beginnings of the heterosis concept. In: Gowen JW, editor. Heterosis. Ames: Iowa State University Press; 1952. p. 14–48.
11. Thakker DA. Heterosis and combining ability studies in castor (*Ricinus communis* L.) [Doctoral thesis]. Gujarat Agricultural University, Sardarkrushinagar, Dantiwada; 2002.
12. Thakker DA, Jadon BS, Patel KM, Patel CJ. Heterosis over environments for seed yield and other attributes in castor (*Ricinus communis* L.). J Oilseeds Res. 2005;22(2):324–326.