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Heterosis studies for seed yield and its contributing characters in castor (*Ricinus communis* L.)

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Abstract

The present investigation was undertaken to estimate heterosis for seed yield and its contributing traits in castor (*Ricinus communis* L.). The crosses were developed using a line $\times$ tester mating design involving four lines and ten testers during *Kharif* 2024-25. The resultant 40 hybrids along with 14 parents and one standard check (GCH 9) were evaluated in a randomized block design with three replications at the Main Oilseeds Research Station, Junagadh Agricultural University, Junagadh during *Kharif* 2025-26. A total of 17 and 4 hybrids exhibited significant desirable heterobeltiosis and standard heterosis, respectively, for seed yield per plant. The heterobeltiosis for seed yield per plant ranged from 41.59 to 65.67 percent, while standard heterosis ranged from 40.67 to 17.16 percent. The highest desirable heterobeltiosis was recorded by JP 107 $\times$ JI 449 (65.67%) followed by JP 109 $\times$ JI 457 (62.92%) and JP 107 $\times$ JI 457 (55.38%). The highest significant positive standard heterosis was exhibited by JP 107 $\times$ JI 437 (17.16%) followed by JP 107 $\times$ JI 462 (16.70%), JP 109 $\times$ JI 457 (16.41%) and JP 107 $\times$ JI 434 (13.44%). Hybrids exhibiting desirable heterosis for important yield-contributing traits such as number of effective branches per plant, number of capsules on primary raceme and 100-seed weight also recorded higher seed yield, indicating the cumulative contribution of these traits towards yield improvement in castor.

Keywords: Heterobeltiosis, standard heterosis, Line $\times$ tester, castor, Junagadh Agricultural University

1. Introduction

Castor (*Ricinus communis* L.) is the most important non-edible oilseed crop cultivated in tropical and subtropical regions worldwide (Weiss, 2000) ^[29]. It belongs to the family Euphorbiaceae and is the sole species of the genus *Ricinus*. The crop is believed to have originated in Egypt, East Africa and India and is now widely grown in countries such as China, Brazil, Thailand, Argentina and the United States (Anjani, 2012) ^[1]. Castor is a cross-pollinated crop with a chromosome number of $2n = 20$. The plant is monoecious, bearing female flowers on the upper portion and male flowers on the lower portion of the raceme. *Ricinus communis* is considered a secondary balanced polyploid with a basic chromosome number of $x = 5$ (Kulkarni, 1959) ^[11]. The species exhibits sexual polymorphism, including monoecious, pistillate and ISF (Interspersed Staminate Flower) (Shiffriss, 1960; Ramachandram and Rangarao, 1988; Lavanya, 2002) ^[13, 24, 27]. During 2024-25, India produced 17.86 lakh tonnes of castor seed from 9.65 lakh hectares of land, with an average productivity of 1852 kg/ha (Anon., 2025) ^[2].

Castor seeds are the main source of castor oil, a colourless to pale-yellow liquid with little to no smell or taste. This oil has more than 1,000 industrial uses, and its demand keeps rising with industrial growth (Ojo and Bello, 2004) ^[18]. Castor seeds comprise 40-60% oil, the highest among all oilseed crops. The oil is rich in triglycerides, primarily ricinoleic acid (80-90%), a unique fatty acid. Due to its high stability and consistent fatty acid content, castor oil serves as an important industrial raw material, essential for producing over 250 industrial products (Yadava *et al.*, 2012) ^[30].

Castor follows a mixed mating system, producing both self-and cross-pollinated offspring. Under natural field conditions, the level of cross-pollination can be quite high, often exceeding 80% (Savy, 2005) ^[26], though it varies depending on the genotype and prevailing environmental conditions.

The expression of sex in castor is highly sensitive to environmental influences (Shiffriess, 1960) [27]. Low temperature (below 30 °C), early-order spikes, a smaller gap between day and night temperature, and good nutrient availability tend to promote the formation of female flowers, thereby increasing femaleness on the spike. Whereas, higher temperature (above 32 °C), later-order spikes, a wider difference between maximum and minimum temperature and poor nutritional conditions encourage the formation of male flowers (Lavanya, 2002) [13].

The utilization of hybrid vigour has been key achievements in this crop. In heterosis breeding, it is essential to carefully assess diverse and promising parental genotypes through their hybrid combinations, especially for seed yield and its associated traits. Identifying superior hybrids based on both the level and direction of heterosis plays an essential role in achieving breeding success. Furthermore, a clear understanding of the extent and nature of genetic variation is important for evaluating the genetic potential of a population.

2. Materials and Methods

The field experiment was conducted at Main Oilseeds Research Station, Junagadh Agricultural University, Junagadh during *Kharif*, 2024-25 and 2025-26. The experimental material of present study was comprised of 40 elite hybrids developed by crossing four lines and ten testers in line × tester mating design along with one standard check (GCH 9). JP 106, JP 107, JP 109 and JP 110 were used as lines and JI 434, JI 437, JI 449, JI 451, JI 456, JI 457, JI 462, JI 471, JI 473 and JI 478 were used as testers. The genotypes were obtained from the Junagadh Agricultural University's Main Oilseeds Research Station in Junagadh.

The crossing programme was carried out during *Kharif*, 2024-25 at Main Oilseeds Research Station, Junagadh Agricultural University, Junagadh. At the same time, the pistillate lines were sib-mated and the male parents were selfed to obtain adequate quantities of pure seed for evaluation in *Kharif* 2025-26. The experimental material consisting of 55 entries, including 14 parents, 40 crosses and one standard check (GCH 9) were tested in randomized block design with three replications during *Kharif*, 2025-26. The space between plants was maintained at 60 cm and 120 cm from row to row. Five competitive plants per genotype in each replication were selected randomly for recording observations on days to 50 percent flowering of primary raceme, days to maturity of primary raceme, number of nodes up to primary raceme, plant height up to primary raceme, total length of the primary raceme, effective length of the primary raceme, number of effective branches per plant, number of capsules on primary raceme, shelling out turn, 100-seed weight, seed yield per plant and oil content.

The analysis of variance for experimental design was performed to test the significance of difference among the genotypes for all the characters as per the method suggested by Panse and Sukhatme. Heterobeltiosis was estimated as per the procedure given by Fonseca and Patterson using mean values for various characters over replications. Standard heterosis referred as the superiority of F_1 over standard hybrid GCH 9 and it was estimated as per the formula given by Meredith and Bridge for various characters over replications.

3. Results and Discussion

3.1 Analysis of variance for experimental design

The analysis of variance was performed to determine the presence of significant variation among genotypes, parents, hybrids and parents vs. hybrids for all twelve characters studied and the results are given in Table 1. The findings showed that the mean sum of squares due to genotypes was highly significant for all the characters. The mean sum of squares attributed to genotypes was further divided into components due to parents, hybrids and parents vs. hybrids. The analysis of variance showed that the mean squares for both parents and hybrids were significant for all the characters, indicating substantial genetic variability among them for the characters studied. The mean squares for parents vs. hybrids were also significant for all the characters except total length of primary raceme, effective length of primary raceme and 100-seed weight. This indicates the existence of substantial heterotic effects for most of the traits studied, with the exception of these three traits.

3.2 Magnitude of heterosis

The percentage increase or reduction in F_1 over the better parent (heterobeltiosis) and over the standard check (standard heterosis) for twelve characters was used to measure heterosis. Standard heterosis is more useful than the measure of heterosis over superior parents. Character-wise results on heterosis over better parent (heterobeltiosis) and over standard check, GW 1339 (standard heterosis) were presented in Table 2 to Table 4.

Early flowering is a desirable trait in castor. Among the 40 crosses studied, 25 hybrids exhibited significant desirable heterobeltiosis and 29 hybrids showed significant negative standard heterosis over the check hybrid GCH 9, indicating earliness. Heterobeltiosis ranged from -11.86 percent (JP 109 × JI 473) to 18.40 percent (JP 107 × JI 437), while standard heterosis varied from -12.43 percent to 14.12 percent. The crosses JP 109 × JI 437, JP 109 × JI 457, JP 110 × JI 471 and JP 110 × JI 478 recorded the highest desirable standard heterosis (-12.43%) followed by JP 106 × JI 471, JP 106 × JI 473, JP 109 × JI 471 and JP 109 × JI 473 (-11.86%). Similar negative heterosis for this trait was also described by Chaudhari and Patel (2014) [5], Makani *et al.* (2015) [16], Gajbhe *et al.* (2017) [10], Punewar *et al.* (2017) [22], Delvadiya *et al.* (2018) [8], Patel *et al.* (2018) [20], Barad *et al.* (2019) [3], Nivedha *et al.* (2023) [17] and Kumari *et al.* (2025) [12].

Out of 40 hybrids, 32 showed significant desirable heterobeltiosis for days to maturity of the primary raceme, while nine hybrids were significantly earlier than the standard check GCH 9. Heterobeltiosis ranged from -17.02% percent (JP 109 × JI 449) to 9.79 percent (JP 107 × JI 456), whereas standard heterosis varied from -6.40 percent (JP 109 × JI 449) to 13.87 percent (JP 107 × JI 451). The cross JP 109 × JI 449 recorded the highest desirable heterobeltiosis (-17.02%) and standard heterosis (-6.40%) followed by JP 109 × JI 462, JP 110 × JI 462, JP 109 × JI 456 and JP 109 × JI 478. Similar negative heterosis for this trait has also demonstrated by Chaudhari and Patel (2014) [5], Makani *et al.* (2015) [16], Punewar *et al.* (2017) [22], Delvadiya *et al.* (2018) [8], Patel *et al.* (2018) [20], Barad *et al.* (2019) [3], Nivedha *et al.* (2023) [17], Chaudhary *et al.* (2024) [7] and Kumari *et al.* (2025) [12].

A lower number of nodes up to the primary raceme is desirable for developing early-maturing and dwarf castor types. Among the 40 hybrids, 23 exhibited significant desirable heterobeltiosis, while only one cross showed significant desirable standard heterosis for this trait. Heterobeltiosis ranged from -20.47 percent (JP 109 × JI 437 and JP 109 × JI 473) to 16.14 percent (JP 107 × JI 449), whereas standard heterosis varied from -13.36 percent (JP 109 ×

JI 456) to 42.86 percent (JP 110 × JI 434). The hybrids JP 109 × JI 437 and JP 109 × JI 473 recorded the highest desirable heterobeltiosis (-20.47%) followed by JP 106 × JI 478 and JP 110 × JI 478. Among all crosses, JP 109 × JI 456 showed the highest desirable standard heterosis (-13.36%) and the lowest number of nodes, indicating its superiority for this trait. Similar findings were also documented by Makani *et al.* (2015) [16], Patted *et al.* (2016) [21], Punewar *et al.* (2017) [22], Barad *et al.* (2019) [3], Nivedha *et al.* (2023) [17], Chaudhary *et al.* (2024) [7] and Kumari *et al.* (2025) [12].

For plant height up to the primary raceme heterobeltiosis ranged from -15.37 percent (JP 106 × JI 449) to 230.82 percent (JP 107 × JI 451), while standard heterosis varied from -27.78 percent (JP 109 × JI 437) to 63.33 percent (JP 110 × JI 457). Among the 40 hybrids, 6 exhibited significant desirable heterobeltiosis and 13 showed significant standard heterosis, of which 5 were in the desirable negative direction. The cross JP 106 × JI 449 recorded the highest desirable heterobeltiosis (-15.37%) followed by JP 106 × JI 471 and JP 106 × JI 457. For standard heterosis, JP 109 × JI 437 showed the maximum desirable value (-27.78%) followed by JP 107 × JI 462, JP 109 × JI 456, JP 109 × JI 462 and JP 109 × JI 478. Similar results have been also observed by Rajani *et al.* (2015) [23], Sapovadiya *et al.* (2015) [25] and Chaudhari *et al.* (2024) [7].

For total length of the primary raceme, three hybrids exhibited significant positive heterobeltiosis, while four hybrids showed significant positive standard heterosis. Heterobeltiosis ranged from -36.52 percent (JP 110 × JI 471) to 21.89 percent (JP 109 × JI 471), whereas standard heterosis varied from -23.14 percent (JP 110 × JI 471) to 27.69 percent (JP 107 × JI 434). The cross JP 109 × JI 471 recorded the highest heterobeltiosis (21.89%), followed by JP 109 × JI 462 and JP 109 × JI 473. For standard heterosis, JP 107 × JI 434 showed the maximum superiority (27.69%) followed by JP 106 × JI 434, JP 110 × JI 434 and JP 109 × JI 434. Similar findings were reported by Chaudhary *et al.* (2011) [6], Makani *et al.* (2015) [16], Delvadiya *et al.* (2018) [8], Patel *et al.* (2018) [20], Barad *et al.* (2019) [3], Yamunara *et al.* (2020) [31], Delvadiya *et al.* (2021) [9], Nivedha *et al.* (2023) [17] and Kumari *et al.* (2025) [12].

For effective length of the primary raceme, only one hybrid exhibited significant positive heterobeltiosis, while eight hybrids showed significant positive standard heterosis and two exhibited significant negative standard heterosis. Heterobeltiosis ranged from -38.72 percent (JP 110 × JI 471) to 20.37 percent (JP 109 × JI 462), whereas standard heterosis varied from -18.91 percent (JP 110 × JI 471) to 46.27 percent (JP 107 × JI 434). The cross JP 109 × JI 462 recorded the highest positive heterobeltiosis (20.37%). For standard heterosis, JP 107 × JI 434 showed the maximum superiority (46.27%) followed by JP 106 × JI 434, JP 109 × JI 434, JP 110 × JI 434 and JP 109 × JI 478. Notably, JP 107 × JI 434 also recorded the greatest effective length of the primary raceme (98.00 cm). Similar positive heterosis for

this trait has been also stated by Chaudhary and Patel (2014) [5], Patted *et al.* (2016) [21], Gajbhe *et al.* (2017) [10], Delvadiya (2018) [8], Barad *et al.* (2019) [3], Yamunara *et al.* (2020) [31], Delvadiya *et al.* (2021) [9], Nivedha *et al.* (2023) [17] and Kumari *et al.* (2025) [12].

Among the 40 hybrids, significant positive heterobeltiosis and standard heterosis for number of effective branches per plant were observed in 12 and 10 crosses, respectively, while significant negative heterobeltiosis and standard heterosis were recorded in 7 and 14 crosses. Heterobeltiosis ranged from -32.90 percent (JP 106 × JI 473) to 48.15 percent (JP 106 × JI 449), with the highest values recorded by JP 106 × JI 449, followed by JP 106 × JI 471, JP 109 × JI 456 and JP 107 × JI 473. Standard heterosis varied from -32.87 percent (JP 106 × JI 434) to 49.65 percent (JP 107 × JI 473). The cross JP 107 × JI 473 exhibited the highest positive standard heterosis (49.65%) followed by JP 107 × JI 456, JP 107 × JI 478, JP 109 × JI 457 and JP 107 × JI 457. The observations conform with the finding of Lavanya and Chandramohan (2003) [14], Patel and Pathak (2006) [19], Rajani *et al.* (2015) [23], Patted *et al.* (2016) [21], Barad *et al.* (2019) [3], Nivedha *et al.* (2023) [17] and Kumari *et al.* (2025) [12].

The number of capsules on the primary raceme is an important yield-contributing trait in castor. Heterobeltiosis ranged from -35.26 percent (JP 110 × JI 449) to 111.37 percent (JP 109 × JI 451), while standard heterosis varied from -20.58 percent (JP 109 × JI 456) to 58.77 percent (JP 109 × JI 471). Significant positive heterobeltiosis and standard heterosis were observed in 18 and 22 hybrids, respectively, whereas significant negative heterosis was recorded in 9 and 7 hybrids, respectively. The cross JP 109 × JI 451 exhibited the highest heterobeltiosis (111.37%), followed by JP 107 × JI 437, JP 109 × JI 471 and JP 107 × JI 462. For standard heterosis, JP 109 × JI 471 recorded the maximum value (58.77%) followed by JP 106 × JI 478, JP 109 × JI 451, JP 106 × JI 449 and JP 107 × JI 437. Notably, JP 109 × JI 471 also produced the highest number of capsules on the primary raceme (139.00). Similar findings were also highlighted by Shridhar *et al.* (2009) [28], Chaudhari *et al.* (2011) [6], Makani *et al.* (2015) [16], Patted *et al.* (2016) [21], Gajbhe *et al.* (2017) [10], Delvadiya *et al.* (2018) [8], Barad *et al.* (2019) [3], Delvadiya *et al.* (2021) [9] and Kumari *et al.* (2025) [12].

For shelling out turn, significant positive heterobeltiosis and standard heterosis were observed in 4 and 6 hybrids, respectively, whereas significant negative heterobeltiosis and standard heterosis were recorded in 16 and 5 hybrids, respectively. Heterobeltiosis ranged from -23.48 percent (JP 110 × JI 473) to 13.26 percent (JP 107 × JI 478), while standard heterosis varied from -15.31 percent (JP 109 × JI 457) to 9.69 percent (JP 109 × JI 449). The cross JP 107 × JI 478 exhibited the highest positive heterobeltiosis (13.26%) followed by JP 107 × JI 471, JP 107 × JI 437 and JP 107 × JI 434. For standard heterosis, JP 109 × JI 449 recorded the maximum value (9.69%), followed by JP 110 × JI 451, JP 110 × JI 437, JP 107 × JI 471 and JP 110 × JI 478. Notably, JP 109 × JI 449 also recorded the highest shelling out turn (71.67%). Lavanya *et al.* (2006) [15], Barad *et al.* (2009) [4], Delvadiya *et al.* (2018) [8], Delvadiya *et al.* (2021) [9] and Kumari *et al.* (2025) [12] reported similar results for this trait. For 100-seed weight, significant positive heterobeltiosis and standard heterosis were observed in 4 and 37 hybrids, respectively, while significant negative heterobeltiosis and

standard heterosis were recorded in 20 and 1 hybrid, respectively. Heterobeltiosis ranged from-30.90 percent (JP 106 × JI 457) to 7.82 percent (JP 107 × JI 437), whereas standard heterosis varied from-6.58 percent (JP 106 × JI 457) to 52.13 percent (JP 106 × JI 462). The cross JP 107 × JI 437 recorded the highest positive heterobeltiosis (7.82%), followed by JP 107 × JI 473, JP 106 × JI 449 and JP 109 × JI 449. For standard heterosis, JP 106 × JI 462 exhibited the maximum superiority (52.13%) followed by JP 107 × JI 462, JP 106 × JI 449, JP 106 × JI 478 and JP 107 × JI 473. Similar positive heterosis for this trait has also suggested by Lavanya and Chandramohan (2003) [14], Shridhar *et al.* (2009) [28], Chaudhari *et al.* (2011) [6], Chaudhari and Patel (2014) [5], Barad *et al.* (2019) [3], Nivedha *et al.* (2023) [17] and Kumari *et al.* (2025) [12].

For seed yield per plant, 17 hybrids exhibited significant positive heterobeltiosis and 4 showed significant positive standard heterosis, whereas significant negative heterobeltiosis and standard heterosis were observed in 6 and 20 hybrids, respectively. Heterobeltiosis ranged from-41.59 percent (JP 106 × JI 473) to 65.67 percent (JP 107 × JI 449), while standard heterosis varied from-40.67 percent (JP 106 × JI 473) to 17.16 percent (JP 107 × JI 437). The highest positive heterobeltiosis was recorded by JP 107 × JI 449 (65.67%) followed by JP 109 × JI 457, JP 107 × JI 434, JP 107 × JI 457 and JP 107 × JI 437. For standard heterosis, JP 107 × JI 437 showed the maximum value (17.16%), followed by JP 107 × JI 462 (16.70%) and JP 109 × JI 457 (16.41%). Notably, JP 107 × JI 437 also recorded the highest seed yield per plant (319.00 g). Similar results was also supported by Lavanya and Chandramohan (2003) [14], Patel and Pathak (2006) [19], Barad *et al.* (2009) [4], Shridhar *et al.* (2009) [28], Makani *et al.* (2015) [16], Patted *et al.* (2016) [21], Delvadiya *et al.* (2018) [8], Barad *et al.* (2019) [3], Chaudhary *et al.* (2024) [7] and Kumari *et al.* (2025) [12].

For oil content, heterobeltiosis ranged from-6.51 percent (JP 106 × JI 457) to 2.55 percent (JP 107 × JI 457), while standard heterosis varied from-6.24 percent (JP 106 × JI 457) to 2.81 percent (JP 110 × JI 456). Among the 40 hybrids evaluated, 18 and 19 hybrids exhibited significant positive heterobeltiosis and standard heterosis, respectively, whereas six hybrids showed significant negative heterobeltiosis. The highest positive standard heterosis was recorded by JP 110 × JI 456 (2.81%) followed by JP 106 × JI 451 (2.62%), JP 109 × JI 471 (2.59%), JP 106 × JI 456 (2.31%) and JP 110 × JI 451 (2.29%). Similar positive heterosis for oil content has also noted by Chaudhari and Patel (2014) [5], Punewar *et al.* (2017) [22], Patel *et al.* (2018)

[20], Barad *et al.* (2019) [3], Nivedha *et al.* (2023) [17] and Kumari *et al.* (2025) [12].

Based on *per se* performance, magnitude of heterosis and significant sca effects the hybrids JP 107 × JI 437, JP 107 × JI 462 and JP 109 × JI 457 was identified as promising for practical plant breeding applications. These crosses displayed superior performance for seed yield per plant and other yield-contributing traits. Among these, JP 107 × JI 437 showed high *per se* performance along with high standard heterosis and desirable sca effects. Likewise, JP 107 × JI 462 and JP 109 × JI 457 also recorded high standard heterosis coupled with favourable sca effects.

In the current study, a wide range of heterotic responses was observed among the different crosses, revealing that the expression of gene action largely relies on the genetic makeup of the parental genotypes involved. Some crosses demonstrated significant positive heterosis, while others displayed negative heterotic effects for various traits, reflecting the diverse genetic potential of the parents used in the experiment. The results clearly suggested the existence of substantial genetic variability in parental genotypes, which contributed to the varied heterotic performance of their hybrids. A detailed of the magnitude of heterosis, along with the number of crosses exhibiting significant positive and negative heterobeltiosis and standard heterosis, is presented in Tables 2 to Table 4.

The four most promising heterotic cross combinations for seed yield per plant were JP 107 × JI 437, JP 107 × JI 462, JP 109 × JI 457 and JP 107 × JI 434. Among these, high-yielding hybrid JP 107 × JI 437 showed significant and desirable standard heterosis for important traits such as number of effective branches/plant, number of capsules on the primary raceme and 100-seed weight. Similarly, the cross JP 107 × JI 462 expressed significant desirable standard heterosis for days to 50 percent flowering of the primary raceme, plant height up to the primary raceme, number of effective branches/plant, number of capsules on the primary raceme and 100-seed weight. The hybrid JP 109 × JI 457 demonstrated significant and desirable standard heterosis for days to 50 percent flowering of the primary raceme, effective length of the primary raceme, number of effective branches/plant, number of capsules on the primary raceme and 100-seed weight. The cross JP 107 × JI 434 expressed significant desirable standard heterosis for total length of primary raceme, effective length of primary raceme, number of effective branches/plant, number of capsules on the primary raceme and 100-seed weight.

Table 1: Analysis of variance (mean squares) for experimental design for different characters in castor

Sources	d.f	Days to 50 percent flowering of primary raceme	Days to maturity of primary raceme	Number of nodes up to primary raceme	Plant height up to primary raceme (cm)	Total length of primary raceme (cm)	Effective length of primary raceme (cm)
Replications	2	2.02	2.27	2.90	2.98	19.90	10.28
Genotypes	53	62.57**	192.75**	13.20**	2642.21**	394.08**	411.68**
Parents (P)	13	49.62**	112.76**	9.30**	5513.12**	872.26**	922.83**
Hybrids (H)	39	61.95**	164.98**	12.45**	1647.99**	243.73**	251.81**
P vs H	1	255.24**	2315.65**	93.34**	4094.87**	41.38	1.69
Error	106	1.99	4.21	0.99	92.87	30.86	25.70

Sources	d.f	Number of effective branches per plant	Number of capsules on primary raceme	Shelling out turn (%)	100-Seed weight (g)	Seed yield per plant (g)	Oil content (%)
Replications	2	0.53	12.69	1.65	0.45	78.24	0.13
Genotypes	53	14.26**	1466.75**	55.01**	48.76**	9073.93**	3.13**
Parents (P)	13	13.52**	1296.71**	73.58**	87.89**	14937.41**	3.92**
Hybrids (H)	39	13.80**	1357.55**	47.27**	36.92**	4641.46**	2.60**
P vs H	1	55.96**	9234.64**	115.57**	1.24	105714.74**	13.46**
Error	106	0.66	60.98	7.33	0.98	394.46	0.05

*, ** Significance at 5% and 1% levels, respectively

Table 2: Percent heterobeltiosis (H₁) and standard heterosis (H₂) for days to 50 percent flowering of primary raceme, days to maturity of primary raceme, plant height up to primary raceme and number of nodes up to primary raceme in castor

Sr. No.	Crosses	Days to 50% flowering of primary raceme		Days to maturity of primary raceme		Number of nodes up to primary raceme		Plant height up to primary raceme (cm)	
		H ₁ (%)	H ₂ (%)	H ₁ (%)	H ₂ (%)	H ₁ (%)	H ₂ (%)	H ₁ (%)	H ₂ (%)
1	JP 106 × JI 434	11.38*	5.08*	-5.19**	2.40	5.70*	28.11**	25.49**	43.33**
2	JP 106 × JI 437	0.00	-7.91**	-0.53**	0.80	-8.75**	10.60	2.41	10.37
3	JP 106 × JI 449	-2.40**	-7.91**	-9.93**	1.60	-11.03**	7.83	-15.37**	-3.33
4	JP 106 × JI 451	-2.40**	-7.91**	-4.83**	-0.27	-7.60**	11.98*	0.19*	14.44
5	JP 106 × JI 456	-2.40*	-7.91**	-2.84**	0.53	0.91**	1.84	-3.91	9.26
6	JP 106 × JI 457	6.92	-3.95*	-9.18**	2.93*	-0.38	20.74**	-8.88**	4.07
7	JP 106 × JI 462	-2.40**	-7.91**	-11.67**	-1.07	2.69**	5.53	18.58	-0.74
8	JP 106 × JI 471	-6.59**	-11.86**	-6.36**	-1.87	-5.63**	0.46	-15.05**	-2.96
9	JP 106 × JI 473	-6.59**	-11.86**	-4.68**	3.20*	-14.07**	4.15	-0.13**	14.07
10	JP 106 × JI 478	-1.81	-7.91**	-3.33**	0.53	-19.01**	-1.84	-4.67**	8.89
11	JP 107 × JI 434	-2.58	6.78**	0.99**	9.07**	13.39	32.72**	211.18**	52.59**
12	JP 107 × JI 437	18.40	9.04**	9.21	10.67**	6.30	24.42**	166.62**	30.74**
13	JP 107 × JI 449	3.59	14.12**	-1.89	10.67**	16.14	35.94**	174.92**	34.81**
14	JP 107 × JI 451	4.32	9.04**	8.65	13.87**	2.36	19.82**	230.82**	62.22**
15	JP 107 × JI 456	-0.58**	-3.95*	9.79	13.60**	0.46**	1.38	160.57	27.78**
16	JP 107 × JI 457	11.95**	0.56	-5.67**	6.40**	3.15	20.74**	122.05*	8.89
17	JP 107 × JI 462	-7.91**	-7.91**	-8.33**	2.67*	-10.76**	-8.29	48.79	-27.04**
18	JP 107 × JI 471	9.41*	5.08*	5.60	10.67**	-6.06**	0.00	191.54	42.96**
19	JP 107 × JI 473	10.56	12.43**	4.68	13.33**	3.94	21.66**	196.07**	45.19**
20	JP 107 × JI 478	2.41**	-3.95*	-0.26**	3.73**	-0.79**	16.13**	121.30**	8.52
21	JP 109 × JI 434	-9.04**	-9.04**	-9.14**	-1.87	-14.17**	0.46	82.68**	-14.07
22	JP 109 × JI 437	-4.91**	-12.43**	-5.00**	-3.73**	-20.47**	-6.91	53.54**	-27.78**
23	JP 109 × JI 449	-10.17**	-10.17**	-17.02**	-6.40**	-7.48**	8.29	85.83**	-12.59

Sr. No.	Crosses	Days to 50% flowering of primary raceme		Days to maturity of primary raceme		Number of nodes up to primary raceme		Plant height up to primary raceme (cm)	
		H ₁ (%)	H ₂ (%)	H ₁ (%)	H ₂ (%)	H ₁ (%)	H ₂ (%)	H ₁ (%)	H ₂ (%)
24	JP 109 × JI 451	-7.34**	-7.34**	-4.58**	0.00	-9.84**	5.53	181.89	32.59**
25	JP 109 × JI 456	-6.43**	-9.60**	-9.02**	-5.87**	-14.16**	-13.36*	63.78**	-22.96**
26	JP 109 × JI 457	-2.52**	-12.43**	-11.74**	0.27	-9.06**	6.45	101.57**	-5.19
27	JP 109 × JI 462	-10.73**	-10.73**	-15.00**	-4.80**	-12.56**	-10.14	64.57	-22.59*
28	JP 109 × JI 471	-8.24**	-11.86**	-4.58**	0.00	-11.69**	-5.99	140.94**	13.33
29	JP 109 × JI 473	-11.86**	-11.86**	-10.59**	-3.20*	-20.47**	-6.91	85.04**	-12.96
30	JP 109 × JI 478	-3.01**	-9.04**	-8.97**	-5.33**	-13.78**	0.92	70.08**	-20.00*
31	JP 110 × JI 434	11.05	7.91**	-0.74**	7.20**	14.81	42.86**	80.09**	54.07**
32	JP 110 × JI 437	-3.07**	-10.73**	-3.42**	-2.13	-12.59**	8.76	-0.43*	-14.81
33	JP 110 × JI 449	-0.58**	-3.39	-3.55**	8.80**	7.78	34.10**	64.50**	40.74**
34	JP 110 × JI 451	-5.23**	-7.91**	-8.91**	-4.53**	-6.67*	16.13**	18.61**	1.48
35	JP 110 × JI 456	-4.68*	-7.91**	-1.55**	1.87	13.24	14.29*	16.88	0.00
36	JP 110 × JI 457	1.26**	-9.04**	-1.17	12.27**	8.52	35.02**	90.91**	63.33**
37	JP 110 × JI 462	-8.72**	-11.30**	-13.57**	-3.20*	0.90**	3.69	9.29	-8.52
38	JP 110 × JI 471	-8.82**	-12.43**	-4.33**	0.27	-3.90**	2.30	29.44**	10.74
39	JP 110 × JI 473	1.16	-1.69	-1.72**	6.40**	-2.22	21.66**	72.29**	47.41**
40	JP 110 × JI 478	-6.63**	-12.43**	-7.44**	-3.73**	-18.52**	1.38	9.96**	-5.93
S.Em±		1.15		1.67		0.81		7.81	
Range		-11.86 to 18.40	-12.43 to 14.12	-17.02 to 9.79	-6.40 to 13.87	-20.47 to 16.14	-13.36 to 42.86	-15.37 to 230.82	-27.78 to 63.33
No. of significant and positive crosses		5	8	1	16	5	16	24	13
No. of significant and negative crosses		25	29	32	9	23	1	6	5

*, ** Significance at 5% and 1% levels, respectively

Table 3: Percent heterobeltiosis (H_1) and standard heterosis (H_2) for total length of primary raceme, effective length of primary raceme, number of effective branches per plant and number of capsules on primary raceme in castor

Sr. No.	Crosses	Total length of primary raceme (cm)		Effective length of primary raceme (cm)		Number of effective branches per plant		Number of capsules on primary raceme	
		H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)
1	JP 106 × JI 434	-15.32**	21.07**	-20.41**	35.82**	28.00*	-32.87**	-0.72	21.98**
2	JP 106 × JI 437	3.10	-6.45	1.40	1.19	1.55	-8.39	-21.39**	-13.93
3	JP 106 × JI 449	3.37	-6.20	1.69	1.49	48.15**	-16.08*	12.73*	47.17**
4	JP 106 × JI 451	-8.56	-16.12**	-6.42	-5.67	10.83	-6.99	-24.83**	-17.69*
5	JP 106 × JI 456	7.01	-2.89	5.86	5.97	8.13	-6.99	22.61**	37.61**
6	JP 106 × JI 457	-12.73*	-0.83	-16.02**	6.97	-11.43*	8.39	-5.13	3.88
7	JP 106 × JI 462	8.38	-1.65	10.17	9.95	-16.15*	-23.78**	16.19*	27.23**
8	JP 106 × JI 471	-10.75	-19.01**	-11.27	-11.44	41.12**	5.59	14.00*	24.82**
9	JP 106 × JI 473	10.66	0.41	10.67	10.45	-32.90**	-27.27**	-23.85**	-16.62*
10	JP 106 × JI 478	3.25	4.96	-0.26	14.43*	-5.07	-8.39	30.67**	54.86**
11	JP 107 × JI 434	-10.69**	27.69**	-14.29**	46.27**	-5.11	14.34*	-3.91	18.06*
12	JP 107 × JI 437	-16.29**	-8.68	-16.06**	2.49	15.00*	28.67**	63.18**	46.84**
13	JP 107 × JI 449	-12.50*	-4.55	-16.06**	2.49	13.15*	23.08**	15.93*	16.66*
14	JP 107 × JI 451	-10.98*	-2.89	-8.31	11.94	-31.25**	-23.08**	21.10*	-12.23
15	JP 107 × JI 456	-17.80**	-10.33	-18.09**	0.00	31.88**	47.55**	15.08*	29.15**
16	JP 107 × JI 457	-10.91*	1.24	-11.72*	12.44*	9.14	33.57**	11.00	14.07*
17	JP 107 × JI 462	-20.08**	-12.81*	-19.72**	-1.99	16.25*	30.07**	54.91**	22.35**
18	JP 107 × JI 471	-12.50*	-4.55	-12.39*	6.97	-5.63	5.59	-17.36*	-18.06*
19	JP 107 × JI 473	-9.62	-1.40	-12.39*	6.97	33.75**	49.65**	35.49**	12.82
20	JP 107 × JI 478	-13.64**	-5.79	-13.20**	5.97	30.63**	46.15**	-1.75	16.44*
21	JP 109 × JI 434	-19.36**	15.29**	-22.86**	31.64**	-14.39	-20.98**	-15.66**	3.62
22	JP 109 × JI 437	0.52	-20.25**	3.07	-13.13*	0.00	-7.69	5.30	-5.25
23	JP 109 × JI 449	3.37	-11.16	8.79	-1.49	1.52	-6.29	-32.09**	-11.34

Sr. No.	Crosses	Total length of primary raceme (cm)		Effective length of primary raceme (cm)		Number of effective branches per plant		Number of capsules on primary raceme	
		H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)
24	JP 109 × JI 451	-5.86	-13.64*	-5.73	-4.98	15.91*	6.99	111.37**	53.20**
25	JP 109 × JI 456	-0.73	-10.33	-4.57	-4.48	36.36**	25.87**	-29.23**	-20.58**
26	JP 109 × JI 457	-6.91	5.79	-6.02	19.70**	13.14*	38.46**	36.95**	40.75**
27	JP 109 × JI 462	18.44*	-12.40*	20.37**	-2.99	-9.85	-16.78*	41.81**	12.01
28	JP 109 × JI 471	21.89**	-14.88**	10.49	-9.85	-1.52	-9.09	60.13**	58.77**
29	JP 109 × JI 473	13.59*	-3.31	9.95	4.48	-19.35**	-12.59	4.97	-12.60
30	JP 109 × JI 478	6.10	7.85	5.38	20.90**	12.32	8.39	-1.09	17.21*
31	JP 110 × JI 434	-16.18**	19.83**	-23.03**	31.34**	-7.32	-20.28**	6.61	30.99**
32	JP 110 × JI 437	-29.01**	-14.05*	-30.83**	-8.46	-6.98	-16.08*	13.30	1.96
33	JP 110 × JI 449	-16.38**	1.24	-15.41**	11.94	-2.44	-16.08*	-35.26**	-15.48*
34	JP 110 × JI 451	-30.03**	-15.29**	-31.58**	-9.45	6.50	-8.39	53.12**	19.69**
35	JP 110 × JI 456	-22.18**	-5.79	-21.05**	4.48	0.81	-13.29	-24.03**	-14.74*
36	JP 110 × JI 457	-18.43**	-1.24	-18.05**	8.46	-32.00**	-16.78*	38.03**	41.85**
37	JP 110 × JI 462	-27.99**	-12.81*	-28.95**	-5.97	-20.00*	-27.27**	1.40	-19.91**
38	JP 110 × JI 471	-36.52**	-23.14**	-38.72**	-18.91**	0.00	-13.99*	-7.97	-8.76
39	JP 110 × JI 473	-20.82**	-4.13	-24.81**	-0.50	-6.45	1.40	46.81**	22.24**
40	JP 110 × JI 478	-15.90**	1.82	-19.02**	7.16	-11.59	-14.69*	4.43	23.75**
S.Em ±		4.56		4.12		0.67		6.38	
Range		-36.52 to 21.89	-23.14 to 27.69	-38.72 to 20.37	-18.91 to 46.27	-32.90 to 48.15	-32.87 to 49.65	-35.26 to 111.37	-20.58 to 58.77
No. of significant and positive crosses		3	4	1	8	12	10	18	22
No. of significant and negative crosses		22	11	22	2	7	14	9	7

*, ** Significance at 5% and 1% levels, respectively

Table 4: Percent heterobeltiosis (H_1) and standard heterosis (H_2) for shelling out turn, 100-seed weight, seed yield per plant and oil content in castor

Sr. No.	Crosses	Shelling out turn (%)		100-seed weight (g)		Seed yield per plant (g)		Oil content (%)	
		H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)
1	JP 106 × JI 434	-0.50	2.55	2.66	38.79**	11.74	-20.76**	-1.43**	-1.16**
2	JP 106 × JI 437	-7.92*	-5.10	-12.43**	18.39**	20.78*	-8.35	-0.30	-0.02
3	JP 106 × JI 449	0.99	4.08	7.59**	45.46**	44.12**	-16.01*	1.96**	2.24**
4	JP 106 × JI 451	-7.43*	-4.59	2.66	38.79**	11.23	-23.38**	2.33**	2.62**
5	JP 106 × JI 456	-12.87**	-10.20**	-13.99**	16.29**	8.34	-11.26	2.02**	2.31**
6	JP 106 × JI 457	-10.89**	-8.16*	-30.90**	-6.58*	21.49*	-13.20*	-6.51**	-6.24**
7	JP 106 × JI 462	0.49	4.08	-14.47**	52.13**	-6.71	-17.29**	0.27	0.56
8	JP 106 × JI 471	-5.94	-3.06	0.92	36.45**	26.10**	7.76	1.87**	2.16**
9	JP 106 × JI 473	-2.97	0.00	-8.96**	23.08**	-41.59**	-40.67**	1.09**	1.90**
10	JP 106 × JI 478	2.48	5.61	2.93	42.01**	-30.04**	-17.31**	0.27	0.77
11	JP 107 × JI 434	9.68**	4.08	3.39	30.76**	59.98**	13.44*	-0.14	-1.66**
12	JP 107 × JI 437	10.33**	3.57	7.82**	31.58**	54.40**	17.16**	1.17**	0.44
13	JP 107 × JI 449	6.42	1.53	-1.58	24.71**	65.67**	-3.45	-0.21	-1.94**
14	JP 107 × JI 451	-0.53	-3.57	3.04	38.84**	19.13*	-17.95**	0.11	0.19
15	JP 107 × JI 456	-1.67	-9.69**	-1.48	20.24**	36.38**	11.70	-1.77**	-1.63**
16	JP 107 × JI 457	0.00	-4.59	-5.39*	15.46**	55.38**	11.02	2.55**	-2.74**
17	JP 107 × JI 462	-3.94	-0.51	-15.36**	50.54**	31.62**	16.70*	1.69**	-2.36**
18	JP 107 × JI 471	12.23**	7.65*	3.35	27.03**	-1.43	-15.77*	2.17**	1.03*
19	JP 107 × JI 473	-1.02	-1.02	7.65**	40.76**	-3.81	-2.30	0.28	1.08**
20	JP 107 × JI 478	13.26**	4.59	-3.11	33.68**	-17.48**	-2.47	-4.54**	-4.06**
21	JP 109 × JI 434	-2.42	3.06	-9.22**	14.82**	28.63**	-8.79	1.23**	1.95**
22	JP 109 × JI 437	-0.97	4.59	-6.83*	4.32	-11.42	-32.79**	0.41	1.13**
23	JP 109 × JI 449	3.86	9.69**	5.62*	33.83**	27.23*	-25.86**	1.13**	1.85**

Sr. No.	Crosses	Shelling out turn (%)		100-seed weight (g)		Seed yield per plant (g)		Oil content (%)	
		H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)
24	JP 109 × JI 451	-1.45	4.08	-10.41**	20.72**	13.15	-22.06**	-0.05	0.66
25	JP 109 × JI 456	-2.9	2.55	-9.85**	-2.78	33.66**	9.48	0.97*	1.69**
26	JP 109 × JI 457	-19.81**	-15.31**	-0.2	7.63*	62.92**	16.41*	-0.81*	-0.11
27	JP 109 × JI 462	-1.45	4.08	-28.97**	26.34**	20.44**	6.78	0.21	0.92*
28	JP 109 × JI 471	-8.7**	-3.57	-9.26**	11.53**	-0.2	-14.72*	1.86**	2.59**
29	JP 109 × JI 473	-1.45	4.08	-11.42**	15.83**	-5.21	-3.72	1.41**	2.21**
30	JP 109 × JI 478	-0.97	4.59	-4.85*	31.28**	-13.16*	2.64	-0.73	-0.02
31	JP 110 × JI 434	-11.3**	4.08	-2.41	23.42**	15.3	-18.24**	0.6	1.07**
32	JP 110 × JI 437	-7.83**	8.16*	-1.41	10.38**	9.33	-17.04**	1.57**	2.04**
33	JP 110 × JI 449	-11.74**	3.57	0.74	27.64**	23.66*	-27.94**	0.03	0.49
34	JP 110 × JI 451	-6.96*	9.18**	-10.68**	20.36**	14.18	-21.35**	1.82**	2.29**
35	JP 110 × JI 456	-10.87**	4.59	1.65	12.18**	8.55	-11.09	2.34**	2.81**
36	JP 110 × JI 457	-20**	-6.12	2.91	13.58**	15.08	-17.78**	-0.49	-0.03
37	JP 110 × JI 462	-9.57**	6.12	-21.69**	39.29**	-3.09	-14.08*	0.08	0.55
38	JP 110 × JI 471	-8.7**	7.14*	-8.55**	12.39**	6.45	-9.04	1.07**	1.54**
39	JP 110 × JI 473	-23.48**	-10.2**	-13.45**	13.17**	-13.52*	-12.17	-2.74**	-1.97**
40	JP 110 × JI 478	-8.26**	7.65*	-11.08**	22.68**	-33.46**	-21.35**	0.13	0.63
S.Em±		2.20		0.81		17.42		0.19	
Range		-23.48 to 13.26	-15.31 to 9.69	-30.90 to 7.82	-6.58 to 52.13	-41.59 to 65.67	-40.67 to 17.16	-6.51 to 2.55	-6.24 to 2.81
No. of significant and positive crosses		4	6	4	37	17	4	18	19
No. of significant and negative crosses		16	5	20	1	6	20	6	9

*, ** Significance at 5% and 1% levels, respectively

4. Conclusion

The present study revealed substantial genetic variability and significant heterosis among the 40 castor hybrids evaluated for seed yield and its associated traits. Significant positive standard heterosis for seed yield per plant was observed in hybrids JP 107 × JI 437, JP 107 × JI 462, JP 109 × JI 457 and JP 107 × JI 434. Among these, JP 107 × JI 437 recorded the highest seed yield per plant along with maximum standard heterosis for seed yield. Several hybrids also exhibited desirable heterosis

for important yield-contributing traits such as number of effective branches, number of capsules on primary raceme and 100-seed weight. The results demonstrated the effectiveness of exploiting hybrid vigour for improving productivity in castor. Based on per se performance, heterotic response and desirable specific combining ability effects, the hybrids JP 107 × JI 437, JP 107 × JI 462 and JP 109 × JI 457 were identified as the most promising combinations for future breeding programmes and commercial exploitation.

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