

Heterosis for Yield and its Components in Castor (*Ricinus communis* L.)

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ABSTRACT

An experiment was conducted to study the nature and magnitude of heterosis for seed yield per plant and its eleven yield attributing components. Experimental material consisting of 55 entries comprised of four pistillate lines (used as females) and ten inbred lines (used as males) and their 40 hybrids developed through line x tester mating design along with standard check hybrid (GCH 7) were evaluated in a randomized block design with three replications. Perusal of mean data revealed that among females, JP 96 and SKP 84 and among males, JI 441, JI 438 and JI 431 exhibited higher per se performance for seed yield per plant and its contributing traits. Three crosses viz., SKP 84 x JI 435, JP 96 x JI 437 and SKP 84 x JI 437 appeared to be the most suitable crosses for exploitation in practical plant breeding programme in castor, as they recorded 39.95 per cent, 29.29 per cent and 35.13 per cent significantly the higher heterosis over their respective better parent, and 15.59 per cent (324.58 g), 14.77 per cent (322.28 g) and 11.61 per cent (313.41 g) significantly the higher heterosis over standard check GCH 7 (280.80 g). These cross combinations also possessed high per se performance for one or more yield contributing traits.

Key words: Castor, heterobeltiosis, standard heterosis.

INTRODUCTION

Castor (*Ricinus communis* L., $2n = 20$) is shrubby tree of the genus *Ricinus* (*Ricinus* is a Latin term for “a kind of tick,” and it refers to the resemblance of castor bean seeds to dog ticks). It belongs to the family *Euphorbiaceae* and its common name is castor bean. Castor is indigenous to Eastern Africa and most probably originated in Ethiopia. The castor plant has been cultivated for centuries for the

oil produced by its seeds. The Egyptians burned castor oil in their lamps more than 4,000 years ago. Castor is one of the most important non-edible oilseed crops in the world. It is generally distributed in the tropical, sub-tropical and warm temperate zones²³. Castor is short-lived small tree or shrub with soft wood and hollow stems which can grow to 5 m or more. Its bark is greenish to reddish brown and smooth.

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Leaves are palmately and deeply lobed with serrate leaf margins, long-stalked, alternate, dark green or even reddish. Its flowers are crowded on upright spikes up to 40 cm long, both sexes occur on the same plant, the upper female flowers appear before the lower male ones. Its fruits are round, deep red, prickly capsules, in dense clusters, containing three tick-like, brown or reddish-brown marbled, very poisonous seeds with high oil content¹⁸.

The phenomenon of heterosis has proved to be the most important genetic tool in enhancing the yield of self as well as cross pollinated species in general and castor in particular. With the availability of cent per cent pistillate lines in castor, exploitation of heterosis or hybrid vigour on commercial scale has become commercially feasible and economical⁶. In Gujarat, real breakthrough in castor production has come with the development and release of hybrids for commercial cultivation. Still, there is potential to further increase in yield level of castor through genetic improvement.

MATERIALS AND METHODS

Experimental material consisting of 55 entries comprised of four pistillate lines (JP 96, JP 104, SKP 84 and SKP 106, used as testers/females) and ten inbred lines (JI 431, JI 432, JI 433, JI 434, JI 435, JI 437, JI 438, JI 439, JI 440 and JI 441, used as lines/males) and their 40 hybrids developed through line x tester mating design along with standard check hybrid (GCH 7) were evaluated in a randomized block design with three replications. The materials were evaluated during *kharif-rabi* 2016-17 at the Sagdividi Farm, Department of Seed Science and Technology, College of Agriculture, Junagadh Agricultural University, Junagadh. Five competitive plants per each entry in each replication were randomly selected before flowering and tagged for the purpose of recording the observations of different characters *viz.*, plant height up to primary

raceme (cm), number of nodes up to primary raceme, length of primary raceme (cm), effective length of primary raceme (cm), number of effective branches per plant, number of capsules on primary raceme, shelling out turn (%), 100 seed weight (g), seed yield per plant (g) and oil content (%). Days to flowering of primary raceme and days to maturity of primary raceme were recorded on plot basis. 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 Sukhatme¹³. Heterobeltiosis was estimated as per the procedure given by Fonseca and Patterson⁴ using mean values for various characters over replications. Standard heterosis referred as the superiority of F₁ over standard hybrid GCH 7 and it was estimated as per the formula given by Meredith and Bridge¹² for various characters over replications.

RESULTS AND DISCUSSION

The analysis of variance was performed to test the significant differences among genotypes, parents, hybrids and parents *vs.* hybrids for all the twelve characters studied and are presented in Table 1. The results revealed that mean squares due to genotypes were highly significant for all the characters. The mean squares due to genotypes were further partitioned into mean squares due to parents, hybrids and parents *vs.* hybrids. The analysis of variance revealed that mean squares due to hybrids differed significantly for all the characters, but mean squares due to parents were significant for all the traits, except shelling out turn, seed yield per plant and oil content. This indicated the existence of considerable genetic variability among the parents and hybrids for all the characters under study. The mean squares due to parents *vs.* hybrids were also significant for all the characters, which indicated that the performance of parents as a group was

different than that of crosses as a group, thereby supporting the presence of mean heterosis for all the traits studied. The results are in accordance to those reported by Ramana *et al*¹⁷, and Sapovadiya *et al*²⁰, in castor.

Considering *per se* performance of hybrids, twenty three hybrids yielded higher than GCH 7 for seed yield per plant, of which three hybrids SKP 84 × JI 435 (324.58 g), JP 96 × JI 437 (322.28 g) and SKP 84 × JI 437 (313.41 g) yielded significantly higher than GCH 7 (280.80 g). Ten superior cross combinations for seed yield per plant placed in based on *per se* performance. Among them, three cross combinations SKP 84 × JI 435, JP 96 × JI 437 and SKP 84 × JI 437 had high *per se* performance along with significant heterobeltiosis and standard heterosis for seed yield per plant. These crosses also manifested the significant positive standard heterosis over GCH 7 for important yield contributing traits like SKP 84 × JI 435 manifested the significant standard heterosis for length of primary raceme, effective length of primary raceme, number of effective branches per plant and number of capsules on primary raceme, JP 96 × JI 437 for days to maturity of primary raceme, length of primary raceme, effective length of primary raceme, number of capsules on primary raceme, shelling out turn and 100 seed weight, and SKP 84 × JI 437 for days to maturity of primary raceme, length of primary raceme, number of effective branches per plant and 100 seed weight (Table 2). This emphasized that high degree of heterosis for seed yield might be attributed to the heterosis observed for these component characters. Similar findings have been reported by Manivel *et al*¹⁰, Sridhar *et al*²¹, Sapovadiya *et al*²⁰, and Patted *et al*¹⁶.

In the present study, heterosis over better parent (heterobeltiosis) and over standard check, GCH 7 (standard heterosis) was estimated. Several crosses exhibited conspicuous level of heterobeltiosis and standard heterosis for different characters are

presented in Table 3A to 3C. Range of heterosis as well as number of crosses exhibited significance positive as well as negative heterobeltiosis and standard heterosis are presented in Table 4.

The magnitude of standard heterosis in the positive direction was high for effective length of primary raceme and length of primary raceme, medium for number of capsules on primary raceme, seed yield per plant, 100 seed weight and number of effective branches per plant, and low for shelling out turn and oil content. Similarly the magnitude of standard heterosis in the negative direction was medium for characters, *viz.*, number of nodes up to the primary raceme, days to maturity of primary raceme, days to flowering of primary raceme and plant height up to primary raceme (Table 4).

With respect to the performance of hybrids for seed yield per plant, it was observed that thirty four hybrids over better parent and three hybrids over standard check (GCH 7) exhibited significant and positive heterosis (Table 4). The range of heterosis over better parent was from **-3.53 to 39.95** per cent, while over standard check, it ranged from **-24.51 to 15.59** per cent. The cross SKP 84 × JI 435 depicted the significantly the highest and positive heterobeltiosis (39.95 %), standard heterosis (15.59 %) as well as the highest seed yield per plant (324.58 g). JP 96 × JI 437 and SKP 84 × JI 437 were the next two best crosses exhibited significant and positive heterobeltiosis (29.29 % and 35.13 %, respectively), standard heterosis (14.77 % and 11.61 %, respectively) and *per se* performance (322.28 g and 313.41 g, respectively). In such cases, expression of heterotic response over better and standard parents indicated the real superiority of hybrids from the commercial point of view. High heterosis for seed yield in castor has also been reported by several workers^{1,2,3,5,7,8,9,10,15,21,22}.

For days to flowering of primary raceme (Table 4), none of cross exhibited

heterobeltiosis in desired (negative) direction, while five crosses were found significantly earlier in flowering of primary raceme over standard check. The cross JP 104 x JI 433 was found earliest among the crosses over standard check followed by JP 104 x JI 434, JP 104 x JI 438, JP 104 x JI 432 and JP 104 x JI 437 (Table 3A). Similarly, for days to maturity of primary raceme, out of 40 hybrids, none of hybrid showed significant and negative heterosis over better parent, while 16 hybrids registered significant and negative heterosis over standard check (Table 4). The cross combination JP 104 x JI 431 recorded significantly the highest desirable heterosis over standard check followed by JP 104 x JI 432, JP 96 x JI 437, SKP 106 x JI 438 and JP 96 x JI 435 (Table 3A). Significant and desirable (negative) heterosis for days to flowering and days to maturity of primary raceme was also reported by Mehta *et al*¹¹., Thakkar *et al*²²., Chaudhari *et al*³., and Patel *et al*¹⁴.

In case of plant height, dwarfness is considered as desirable attribute in castor. Out of 40 hybrids, none of hybrid exhibited significant and negative heterobeltiosis, while only one hybrid JP 104 x JI 439 manifested the significant and desirable standard heterosis over GCH-7 for plant height up to primary raceme (Table 4). Significant and negative heterosis for plant height up to primary raceme has been reported by Mehta *et al*¹¹., Manivel *et al*¹⁰., Joshi *et al*⁷., Golakia *et al*⁵., Patel and Pathak¹⁵ and Patel *et al*¹⁴.

Minimum number of nodes is being desirable in castor. None of the cross showed significant and desirable (negative) heterobeltiosis for this trait, while on the other hand, significant and desirable (negative) standard heterosis was observed in six cross combinations (Table 4). The five cross combinations *viz.*, JP 104 x JI 431, JP 104 x JI 439, JP 96 x JI 433, JP 104 x JI 437 and JP 104 x JI 432 recorded significantly the highest and desirable magnitude of standard heterosis

were the best standard heterotic hybrids for number of nodes up to primary raceme (Table 3A). Similar findings confirmed with the results of those reported by Manivel *et al*¹⁰., Joshi *et al*⁷., and Thakkar *et al*²²., for this trait.

The cross combination JP 104 x JI 432 exhibited significant and desirable standard heterosis for number of node up to primary raceme (-15.19 %) also exhibited significant and desirable standard heterosis for days to flowering of primary raceme (-8.04 %) and days to maturity of primary raceme (-9.92 %). JP 104 x JI 437 (-15.56 %) also exhibited significant and desirable standard heterosis for days to flowering of primary raceme (-7.67 %). JP 104 x JI 439 cross combination, which exhibited significant and desirable standard heterosis for number of node up to primary raceme (-17.04 %) also exhibited significant and desirable standard heterosis for plant height up to primary raceme (-10.69%) (Table 3A).

The number of cross combinations that exceeded over better parent and standard check for length of primary raceme were sixteen and eleven crosses, respectively (Table 4). JP 96 x JI 435, JP 96 x JI 432, JP 96 x JI 431, SKP 106 x JI 441 and JP 96 x JI 433 were the other best cross combinations with respect to standard heterosis for length of primary raceme (Table 3B). Similarly, for effective length of primary raceme, fourteen hybrids exhibited significant and positive heterosis over better parent, whereas nine hybrids exhibited significant and positive heterosis over standard check (Table 4). Similar to length of primary raceme, same cross JP 96 x JI 435 exhibited significantly the maximum and positive standard heterosis as well as heterobeltiosis for this trait. JP 96 x JI 432, JP 96 x JI 431, SKP 84 x JI 435 and SKP 106 x JI 441 were the other standard heterotic cross combination showing significant and positive heterosis over GCH 7 for effective length of main raceme (Table 3B). Similar findings for length of primary raceme have also been

reported by Mehta *et al*¹¹., Manivel *et al*¹⁰., Golakia *et al*⁵., Sridhar *et al*²¹., Patel *et al*¹⁴., and Patted *et al*¹⁶.

Twenty three and six cross combinations exhibited significant and positive heterosis over better parent and standard hybrid, respectively for number of effective branches per plant (Table 4). It had direct relationship with positive increase in seed yield per plant. The cross combination JP 96 x JI 432 exhibited significantly the highest and positive standard heterosis for number of effective branches per plant followed by SKP 84 x JI 437, JP 96 x JI 435, JP 96 x JI 431, SKP 106 x JI 438 and SKP 84 x JI 435 (Table 3B). The highest estimate of heterobeltiosis (42.45 %) was recorded by SKP 84 x JI 437. Positive estimation of heterosis for this trait was also reported by Mehta *et al*¹¹., Joshi *et al*⁷., Lavanya and Chandramohan⁸, Patel and Pathak¹⁵ and Patted *et al*¹⁶.

Number of capsules on primary raceme is a major factor governing the seed yield in castor. The number of cross combinations which exceeded better and standard parental values for number of capsules on primary raceme was fourteen and eleven crosses, respectively (Table 4). The present findings indicated that this character has wide genetic base in the population and still better results could be achieved by isolating desirable cross combinations with different parentage. The cross combination SKP 106 x JI 437 exhibited significantly the highest and positive standard heterosis followed by JP 96 x JI 431, SKP 106 x JI 435, SKP 106 x JI 441 and JP 96 x JI 437 (Table 3B). The top performing hybrid (SKP 106 x JI 437) for number of capsules on primary raceme (115.56) also recorded the significant and positive heterobeltiosis (27.60 %) and standard heterosis (18.34 %) for this trait. High magnitude of desirable heterosis for this trait was also reported by Mehta *et al*¹¹., Manivel *et al*¹⁰., Joshi *et al*⁷., Sridhar *et al*²¹., and Patted *et al*¹⁶.

In case of shelling out turn, eleven hybrids showed significant and positive

heterosis over better parent and six hybrids exhibited significant and positive heterosis over standard check (Table 4). Out of six hybrids, JP 96 x JI 440 (8.04 %), JP 96 x JI 433 (7.58 %) and JP 104 x JI 441 (7.57 %) registered significantly the maximum and positive standard heterosis, for shelling out turn (Table 3C). The cross combination SKP 106 x JI 434 exhibited significantly the highest and positive magnitude of heterobeltiosis followed by SKP 106 x JI 435 and SKP 106 x JI 431. As observed in the present study, low magnitude of heterobeltiosis was also reported by Saiyed *et al*¹⁹., in castor.

For 100 seed weight, eighteen crosses expressed significant and positive heterobeltiosis, while thirteen crosses exhibited significant and positive standard heterosis (Table 4). The cross combinations SKP 84 x JI 431 exhibited significantly the maximum heterobeltiosis (20.72 %) and standard heterosis (15.54 %) for test weight. JP 104 x JI 439, JP 96 x JI 441, SKP 84 x JI 441 and SKP 106 x JI 431 were the next four superior crosses for test weight, as they displayed significant and positive standard heterosis (Table 3C). Significant estimates of heterosis for 100 seed weight have been reported by Manivel *et al*¹⁰., Joshi *et al*⁷., Lavanya and Chandramohan, Golakia *et al*⁵., Sridhar *et al*²¹. and Patel *et al*¹⁴.

Six hybrids manifested significant and positive heterosis over better parent for oil content, while two hybrids exhibited significant and positive heterosis over standard check for oil content (Table 4). The cross SKP 106 x JI 434 exhibited significantly the highest and positive heterosis over better parent followed by SKP 106 x JI 435 and SKP 106 x JI 431. The crosses SKP 106 x JI 434 (7.07 %) and JP 96 x JI 431 (6.96 %) recorded significantly the maximum and positive magnitude of standard heterosis for oil content (Table 3C). Significant estimates of heterosis have been reported by Joshi *et al*⁷., Lavanya and Chandramohan⁸ and Patel *et al*¹⁴., for this trait.

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

Sources	d.f.	Days to flowering of primary raceme		Days to maturity of primary raceme		Plant height up to primary raceme (cm)		Number of nodes up to primary raceme		Length of primary raceme (cm)		Effective length of primary raceme (cm)	
Replications	2	10.14		41.05		38.58		3.60		29.85		19.54	
Genotypes	53	35.35	**	76.39	**	158.12	**	5.76	**	185.04	**	179.26	**
Parents (P)	13	19.93	**	70.34	**	206.90	**	6.36	**	137.04	**	106.43	**
Hybrids (H)	39	29.51	**	66.13	**	123.60	**	4.67	**	147.84	**	166.95	**
Parents vs. Hybrids	1	463.36	**	554.81	**	870.11	**	40.46	**	2060.01	**	1606.00	**
Error	106	6.50		17.64		18.30		1.96		27.16		22.44	

Table 1: Contd...

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	0.19		645.99	**	23.13		2.96		5372.66	**	1.96	
Genotypes	53	3.37	**	312.87	**	43.29	**	24.94	**	3326.31	**	7.10	**
Parents (P)	13	0.82	**	171.54	**	12.83		12.19	**	570.79		3.05	
Hybrids (H)	39	2.41	**	233.94	**	44.23	**	20.27	**	1322.99	**	5.54	**
Parents vs. Hybrids	1	73.73	**	5228.28	**	402.57	**	372.64	**	117289.24	**	120.54	**
Error	106	0.27		36.27		13.19		4.87		316.89		2.15	

** Significant at 1 per cent levels of significance

Table 2: Promising hybrids for seed yield per plant with heterobeltiosis (H_1) and standard heterosis (H_2) and component traits showing significant desirable standard heterosis

Sr. No.	Hybrids	Seed yield per plant (g)	Heterosis (%)				Significant desirable standard heterosis for component traits
			H_1		H_2		
1	SKP 84 × JI 435	324.58	39.95	**	15.59	**	LR, ELR, EB, CR,
2	JP 96 × JI 437	322.28	29.29	**	14.77	**	DM, LR, ELR, CR, ST, SW
3	SKP 84 × JI 437	313.41	35.13	**	11.61	*	DM, LR, EB, SW
4	SKP 106 × JI 432	308.88	37.88	**	10.00		DM, CR, ELR,
5	SKP 106 × JI 441	307.14	31.13	**	9.38		LR, ELR, CR, SW
6	SKP 106 × JI 438	306.49	32.93	**	9.15		DM, EB, CR, SW
7	JP 96 × JI 435	303.86	21.90	**	8.21		DM, LR, ELR, EB
8	JP 104 × JI 441	302.62	29.20	**	7.77		CR, ST, SW,
9	SKP 106 × JI 435	301.05	34.39	**	7.21		CR
10	SKP 84 × JI 431	298.28	28.61	**	6.22		LR, CR, ST, SW
	GCH 7	280.80					
	S.Em	10.23	14.80		14.80		

*, ** Significant at 5 per cent and 1 per cent levels of significance, respectively

DM= Days to maturity of primary raceme, LR= Length of primary raceme, ELR= Effective length of primary raceme, CR= Number of capsules on primary raceme, EB= Number of effective branches per plant, SW= 100 seed weight, ST= Shelling out turn

Table 3A: Per cent heterosis over better parent (H₁) and standard check (H₂) for days to 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

Hybrids	Days to flowering of primary raceme			Days to maturity of primary raceme			Plant height up to primary raceme (cm)			Number of nodes up to primary raceme					
	H ₁ (%)	H ₂ (%)		H ₁ (%)	H ₂ (%)		H ₁ (%)	H ₂ (%)		H ₁ (%)	H ₂ (%)				
JP 96 × JI 431	8.20	*	-3.20	4.40		-7.79	**	28.34	**	15.03	**	5.75		-11.48	
JP 96 × JI 432	12.59	**	0.74	7.46	*	-5.33		50.24	**	31.00	**	12.39		-2.59	
JP 96 × JI 433	8.59	*	-4.21	5.10		-3.04		45.47	**	12.91	*	6.57		-15.93	*
JP 96 × JI 434	11.89	**	0.11	6.36	*	-1.88		6.86		12.06	*	6.45		-2.22	
JP 96 × JI 435	11.84	**	0.06	2.68		-7.83	**	37.14	**	30.90	**	4.05		-4.81	
JP 96 × JI 437	7.72	*	-3.62	1.98		-9.67	**	14.84	**	19.58	**	7.76		-2.22	
JP 96 × JI 438	6.19		-4.99	4.93		-3.19		17.48	**	12.38	*	-0.40		-8.89	
JP 96 × JI 439	12.44	**	0.60	7.12	*	-5.41		17.69	**	14.07	**	0.00		-11.11	
JP 96 × JI 440	6.04		-5.13	8.51	**	0.11		29.03	**	29.23	**	11.69		2.59	
JP 96 × JI 441	14.09	**	2.08	8.81	**	0.38		9.79	*	18.62	**	13.22		-4.81	
JP 104 × JI 431	6.15		-4.59	-2.17		-13.59	**	14.18	*	-0.48		6.76		-18.15	**
JP 104 × JI 432	2.19		-8.04	2.26		-9.92	**	14.28	*	-0.39		10.63		-15.19	*
JP 104 × JI 433	-0.08		-11.86	4.63		-4.86		34.42	**	4.33		17.87	*	-9.63	
JP 104 × JI 434	0.49		-9.57	3.06		-6.29	*	19.25	**	3.94		19.32	*	-8.52	
JP 104 × JI 435	12.07	**	0.85	2.81		-6.95	*	15.81	**	0.94		21.26	*	-7.04	
JP 104 × JI 437	2.60		-7.67	4.11		-7.79	**	12.89	*	-1.60		10.14		-15.56	*
JP 104 × JI 438	1.51		-8.65	3.58		-5.82	*	9.14		-4.87		13.04		-13.33	*
JP 104 × JI 439	9.10	*	-1.82	4.39		-7.82	**	2.46		-10.69	*	8.21		-17.04	**
JP 104 × JI 440	11.48	**	0.32	8.14	**	-1.67		9.99		-4.13		22.71	**	-5.93	
JP 104 × JI 441	16.05	**	4.43	6.85	*	-2.85		6.71		-6.98		18.84	*	-8.89	

Table 3A: Contd...

Hybrids	Days to flowering of primary raceme				Days to maturity of primary raceme				Plant height up to primary raceme (cm)				Number of nodes up to primary raceme			
	H ₁ (%)		H ₂ (%)		H ₁ (%)		H ₂ (%)		H ₁ (%)		H ₂ (%)		H ₁ (%)		H ₂ (%)	
SKP 84 × JI 431	19.04	**	7.00	*	14.41	**	1.05		16.10	**	4.06		16.37	*	-2.59	
SKP 84 × JI 432	15.37	**	4.12		13.75	**	0.21		18.69	**	3.49		10.26		-4.44	
SKP 84 × JI 433	19.62	**	5.52		8.34	**	2.38		30.52	**	1.31		17.37	*	-7.41	
SKP 84 × JI 434	8.56	*	-2.30		7.12	*	2.47		10.01		1.37		-2.25		-3.33	
SKP 84 × JI 435	10.96	**	5.06		10.21	**	-0.25		12.52	*	3.69		10.53		1.11	
SKP 84 × JI 437	4.59		-0.21		6.34	*	-5.89	*	4.23		-3.96		13.47		2.96	
SKP 84 × JI 438	11.64	**	6.40		6.99	*	-0.43		3.19		-4.92		22.67	**	12.22	
SKP 84 × JI 439	16.43	**	7.09	*	10.02	**	-2.85		6.96		-1.43		13.33		0.74	
SKP 84 × JI 440	9.68	**	6.48		5.24		3.06		14.25	*	5.28		4.15		2.22	
SKP 84 × JI 441	5.86		6.19		5.49		2.28		12.84	*	3.98		32.60	**	11.48	
SKP 106 × JI 431	11.71	**	0.41		4.89		-7.35	**	20.58	**	-5.50		20.87	*	-7.78	
SKP 106 × JI 432	7.70	*	-2.80		7.23	*	-5.54	*	27.05	**	-0.43		23.79	**	-5.56	
SKP 106 × JI 433	7.58		-5.09		3.03		-2.65		31.45	**	2.03		30.10	**	-0.74	
SKP 106 × JI 434	7.40		-3.35		4.22		-0.31		31.94	**	3.40		31.07	**	0.00	
SKP 106 × JI 435	9.00	*	0.70		7.06	*	-3.10		19.77	**	-6.14		20.39	*	-8.15	
SKP 106 × JI 437	5.20		-2.81		5.43		-6.61	*	22.33	**	-4.13		20.39	*	-8.15	
SKP 106 × JI 438	4.62		-3.34		-1.42		-8.10	**	28.00	**	0.32		25.24	**	-4.44	
SKP 106 × JI 439	9.02	*	0.27		5.93		-6.46	*	29.49	**	1.48		32.52	**	1.11	
SKP 106 × JI 440	13.18	**	4.57		2.21		-1.41		26.25	**	-1.06		33.50	**	1.85	
SKP 106 × JI 441	9.88	*	1.51		2.48		-1.15		32.59	**	3.91		25.73	**	-4.07	
Mean Heterosis	9.20		-0.71		5.59		-3.79		19.86		4.56		15.45		-5.09	
S.Em ±	2.21		2.21		3.35		3.35		3.23		3.23		1.15		1.15	

Table 3B: Per cent heterosis over better parent (H₁) and standard check (H₂) for length of primary raceme, effective length of primary raceme, number of effective branches per plant and number of capsules on primary raceme in castor

Hybrids	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 (%)	
JP 96 × JI 431	27.62	**	16.59	**	26.49	**	16.28	**	23.77	**	12.18	*	5.86		14.07	*
JP 96 × JI 432	34.30	**	28.01	**	34.89	**	26.96	**	26.89	**	15.01	**	-12.88	*	-6.13	
JP 96 × JI 433	27.80	**	12.63	*	23.31	**	11.39	*	21.19	**	9.84		2.94		10.92	
JP 96 × JI 434	-3.84		-6.43		-3.15		-6.38		6.56		-3.42		-11.19	*	-4.31	
JP 96 × JI 435	48.37	**	28.10	**	41.98	**	28.26	**	23.86	**	12.26	*	1.32		9.17	
JP 96 × JI 437	18.84	*	11.85	*	19.86	**	12.17	*	1.64		-7.88		5.54		13.72	*
JP 96 × JI 438	2.99		-11.08		-3.43		-12.76	*	13.93	*	3.27		-7.44		-0.27	
JP 96 × JI 439	-6.20		-11.45		-9.02		-13.76	*	-6.56		-15.30	**	-0.38		7.34	
JP 96 × JI 440	13.95	*	11.71	*	16.28	**	11.09		-3.28		-12.33	*	2.65		10.60	
JP 96 × JI 441	5.22		3.97		9.06		4.45		9.43		-0.82		-10.47	*	-3.53	
JP 104 × JI 431	9.63		0.15		9.55		0.71		13.12	*	0.85		-3.36		-12.72	*
JP 104 × JI 432	5.74		0.79		6.04		-0.19		9.17		-2.67		-3.74		-13.06	*
JP 104 × JI 433	19.02	**	4.89		17.90	**	5.20		10.83		-1.19		1.83		-8.02	
JP 104 × JI 434	2.79		0.01		2.63		-0.79		-0.83		-11.59	*	3.06		-6.91	
JP 104 × JI 435	13.81		-9.13		1.47		-17.56	**	20.00	**	6.98		1.77		-8.08	
JP 104 × JI 437	7.69		1.35		6.01		-1.39		9.17		-2.67		15.80	*	4.60	
JP 104 × JI 438	16.97	*	-6.17		8.32		-12.97	*	17.50	**	4.75		-6.98		-15.98	**
JP 104 × JI 439	-2.19		-7.67		-10.18		-14.86	*	-3.33		-13.82	**	0.14		-9.55	
JP 104 × JI 440	-2.74		-4.66		-11.40		-15.36	**	11.67	*	-0.45		-10.09		-18.79	**
JP 104 × JI 441	1.61		0.41		6.72		2.21		8.33		-3.42		23.84	**	11.86	*

Table 3B: Contd...

Hybrids	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 (%)	
SKP 84 × JI 431	21.76	**	11.27	*	13.36	*	4.20		13.21	*	-10.85	*	19.42	**	12.01	*
SKP 84 × JI 432	-1.43		-6.04		-6.57		-12.07	*	33.35	**	5.01		8.58		1.83	
SKP 84 × JI 433	5.38		-7.12		-2.46		-12.97	*	22.43	**	-2.67		12.43	*	5.44	
SKP 84 × JI 434	-1.34		-4.01		-2.43		-5.68		19.81	**	-5.65		-6.29		-12.11	*
SKP 84 × JI 435	39.51	**	11.79	*	38.47	**	12.51	*	41.86	**	11.81	*	19.42	**	12.00	*
SKP 84 × JI 437	18.87	*	11.88	*	14.38		6.45		42.45	**	12.26	*	9.46		2.66	
SKP 84 × JI 438	25.72	**	0.84		26.58	**	1.71		17.92	**	-7.13		-3.81		-9.79	
SKP 84 × JI 439	-3.20		-8.62		-7.65		-12.47	*	15.09	*	-9.36		9.73		2.91	
SKP 84 × JI 440	-8.16		-9.96		-10.46		-14.46	*	27.78	**	2.53		-3.82		-9.80	
SKP 84 × JI 441	4.66		3.42		10.16		5.50		26.08	**	-0.71		10.95		4.06	
SKP 106 × JI 431	17.53	*	12.03	*	-2.39		-10.27		22.02	**	-1.19		20.86	**	12.10	*
SKP 106 × JI 432	-2.75		11.10		20.88	**	13.78	*	-12.84	*	-29.42	**	19.91	**	11.21	*
SKP 106 × JI 433	14.45	*	0.80		12.58	*	0.46		24.77	**	1.04		9.81		1.84	
SKP 106 × JI 434	12.35	*	9.32		15.62	**	11.77	*	-9.17		-26.45	**	15.81	*	7.41	
SKP 106 × JI 435	10.34		-6.11		8.99		-7.48		-6.42		-24.22	**	22.83	**	13.92	*
SKP 106 × JI 437	-8.90		-14.26	*	-5.47		-12.07	*	0.92		-18.28	**	27.60	**	18.34	**
SKP 106 × JI 438	10.93		-5.60		10.64		-6.08		37.96	**	11.81	*	20.49	**	11.75	*
SKP 106 × JI 439	7.02		1.03		8.12		2.49		7.34		-13.08	*	13.19	*	4.98	
SKP 106 × JI 440	-3.88		-5.77		-1.69		-6.08		8.26		-12.33	*	18.13	**	9.56	
SKP 106 × JI 441	14.17	*	12.81	*	17.44	**	12.49	*	26.61	**	2.53		22.68	**	13.79	*
Mean Heterosis	10.36		2.06		8.78		-0.13		14.31		-3.11		6.64		2.26	
S.Em ±	4.21		4.21		3.78		3.78		0.44		0.44		5.48		5.48	

*, ** Significant at 5 per cent and 1 per cent levels of significance, respectively

Table 3C: Per cent heterosis over better parent (H₁) and standard check (H₂) for shelling out turn, 100 seed weight, seed yield per plant and oil content in castor

Hybrids	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 (%)	
JP 96 × JI 431	3.23		7.04		0.29		3.26		14.84	*	1.94		4.59		6.96	*
JP 96 × JI 432	2.39		6.16		6.74		9.90		11.65		-0.89		-0.21		0.14	
JP 96 × JI 433	3.76		7.58	*	6.37		9.52		14.59	*	1.72		0.39		0.75	
JP 96 × JI 434	-8.82	*	-5.46		-7.72		-4.99		7.93		-4.19		1.24		1.59	
JP 96 × JI 435	2.31		6.08		3.47		6.53		21.90	**	8.21		3.04		3.41	
JP 96 × JI 437	3.63		7.45	*	10.15		13.41	*	29.29	**	14.77	**	1.87		2.23	
JP 96 × JI 438	2.89		6.68		8.55		11.77	*	17.85	**	4.62		0.45		0.81	
JP 96 × JI 439	1.55		5.29		2.44		5.48		11.31		-1.19		3.26		3.62	
JP 96 × JI 440	4.20		8.04	*	7.33		10.51		7.17		-4.86		1.47		1.82	
JP 96 × JI 441	2.61		6.39		11.68	*	14.99	**	18.48	**	5.18		0.62		0.98	
JP 104 × JI 431	-3.46		-4.43		13.67	*	8.80		17.08	**	-4.12		4.39		2.16	
JP 104 × JI 432	6.85		5.78		19.81	**	13.22	*	32.06	**	3.34		0.53		0.47	
JP 104 × JI 433	8.06	*	6.98		7.35		1.45		26.18	**	-1.27		2.72		0.54	
JP 104 × JI 434	0.44		-0.57		11.97	*	11.11	*	30.15	**	3.43		-0.12		-2.25	
JP 104 × JI 435	-0.02		-1.02		12.67	*	6.48		27.92	**	0.09		3.25		1.05	
JP 104 × JI 437	7.49	*	6.42		-0.97		-0.16		21.10	**	-3.18		4.34		2.12	
JP 104 × JI 438	8.06	*	6.98		14.42	*	9.40		14.99	*	-5.59		-1.08		-3.19	
JP 104 × JI 439	0.00		-1.00		16.68	**	15.44	**	16.61	*	-7.24		-1.71		-3.81	
JP 104 × JI 440	-4.60		-4.82		13.14	*	9.20		-3.53		-24.51	**	3.81		1.59	
JP 104 × JI 441	7.70	*	7.57	*	10.98	*	12.92	*	29.20	**	7.77		5.10		2.86	

Table 3C: Contd...

Hybrids	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 (%)	
SKP 84 × JI 431	7.91	*	7.53	*	20.72	**	15.54	**	28.61	**	6.22		0.49		-3.17	
SKP 84 × JI 432	7.40	*	7.04		12.03	*	4.97		15.98	*	-4.21		-3.08		-3.13	
SKP 84 × JI 433	6.63		6.27		16.11	**	8.80		22.41	**	1.11		3.29		-0.47	
SKP 84 × JI 434	-2.59		-2.93		7.61		6.78		13.53	*	-6.23		6.04	*	2.18	
SKP 84 × JI 435	-3.09		-3.42		12.14	*	5.07		39.95	**	15.59	**	4.56		0.75	
SKP 84 × JI 437	6.58		6.21		12.45	*	13.46	*	35.13	**	11.61	*	5.48		2.94	
SKP 84 × JI 438	-3.61		-3.94		0.11		-4.29		19.14	**	-1.60		0.57		-3.09	
SKP 84 × JI 439	-4.32		-4.65		8.55		7.39		22.15	**	0.89		-0.33		-3.47	
SKP 84 × JI 440	-4.59		-4.80		8.55		4.77		9.73		-9.37		7.39	*	3.47	
SKP 84 × JI 441	7.49	*	7.37	*	12.07	*	14.03	*	23.42	**	2.95		-0.73		-2.85	
SKP 106 × JI 431	11.96	**	6.58		18.67	**	13.65	*	28.75	**	5.44		7.41	*	3.02	
SKP 106 × JI 432	-2.63		-4.73		15.06	*	-3.88		37.88	**	10.00		3.41		3.36	
SKP 106 × JI 433	-2.65		-4.92		2.65		-6.30		32.87	**	6.00		7.02	*	2.98	
SKP 106 × JI 434	12.66	**	6.72		-5.38		-6.10		23.87	**	-1.18		9.56	**	7.07	*
SKP 106 × JI 435	12.13	**	6.21		-7.01		-13.05	*	34.39	**	7.21		7.46	*	3.06	
SKP 106 × JI 437	8.37	*	6.69		-9.25		-8.51		14.80	*	-8.21		-1.94		-4.30	
SKP 106 × JI 438	-2.17		-6.71		18.62	**	13.43	*	32.93	**	9.15		0.84		-3.28	
SKP 106 × JI 439	-0.59		-5.84		-3.76		-4.79		30.23	**	3.89		-0.27		-3.41	
SKP 106 × JI 440	6.83		6.60		-8.48		-11.66	*	20.74	**	-3.68		1.21		-2.93	
SKP 106 × JI 441	6.67		6.55		9.49		11.40	*	31.13	**	9.38		4.83		2.60	
Mean Heterosis	2.91		2.72		7.74		5.72		22.11		1.22		2.52		0.62	
S.Em ±	2.61		2.61		1.76		1.76		14.80		14.80		1.33		1.33	

*, ** Significant at 5 per cent and 1 per cent levels of significance, respectively

Table 4: Range of heterobeltiosis (H_1) and standard heterosis (H_2) along with number of crosses showing significant heterosis for various characters in castor

Sr. No.	Characters	Range of heterosis (%)		Number of crosses showing significant heterosis			
		H_1 (%)	H_2 (%)	H_1 (%)		H_2 (%)	
				+Ve	-Ve	+Ve	-Ve
1	Days to flowering of primary raceme	-0.08 to 19.62	-11.86 to 7.09	26	0	2	5
2	Days to maturity of primary raceme	-2.17 to 14.41	-13.59 to 3.06	17	0	0	16
3	Plant height up to primary raceme (cm)	2.46 to 50.24	-10.69 to 31.00	31	0	10	1
4	Number of nodes up to primary raceme	-2.25 to 33.50	-18.15 to 12.22	19	0	0	6
5	Length of primary raceme (cm)	-8.90 to 48.37	-14.26 to 28.10	16	0	11	1
6	Effective length of primary raceme (cm)	-11.40 to 41.98	-17.56 to 28.26	14	0	9	11
7	Number of effective branches per plant	-12.84 to 42.45	-29.42 to 15.01	23	1	6	11
8	Number of capsules on primary raceme	-12.88 to 27.60	-18.79 to 18.34	14	3	11	5
9	Shelling out turn (%)	-8.82 to 12.66	-6.71 to 8.04	11	1	6	0
10	100 seed weight (g)	-9.25 to 20.72	-13.05 to 15.54	18	0	13	2
11	Seed yield per plant (g)	-3.53 to 39.95	-24.51 to 15.59	34	0	3	1
12	Oil content (%)	-3.08 to 9.56	-4.30 to 7.07	6	0	2	0

CONCLUSION

From the results and discussion, it can be concluded that considerable heterobeltiosis and standard heterosis observed for seed yield and other associated characters suggested the presence of large genetic diversity among the parents and also unidirectional distribution of allelic constitution contributing towards desirable heterosis in the present material. The moderate to low magnitude of desirable heterosis observed for days to flowering of primary raceme, days to maturity of primary raceme, plant height up to primary raceme, number of nodes up to primary raceme, shelling out turn and oil content indicated the narrow genetic base among the parents. Three crosses viz., SKP 84 x JI 435, JP 96 x JI 437 and SKP 84 x JI 437 appeared to be the most suitable crosses for exploitation in practical plant breeding programme in castor, as they recorded 39.95 per cent, 29.29 per cent and 35.13 per cent significantly the higher heterosis over their respective better parent, and 15.59 per cent (324.58 g), 14.77 per cent (322.28 g) and 11.61 per cent (313.41 g) significantly the higher heterosis over standard check GCH 7 (280.80 g).

REFERENCES

1. Barad, Y.M., Pathak, A.R. and Patel, B.N., Heterosis for yield and yield attributing traits in castor (*Ricinus communis* L.). *J. Oilseeds Res.*, **26**(2): 102-104 (2009).
2. Chaudhari, G. and Patel, B. N., Heterosis and combining ability analysis for oil yield and its components in castor (*Ricinus communis* L.). *Trends Biosci.*, **7**(22): 3757-3760 (2014).
3. Chaudhari, K.N., Chaudhary, R.F., Patel, D.K., Patel, H.N., Pathak, H.C. and Prajapari, B.H., Heterosis for seed yield and yield components over environments in castor (*Ricinus communis* L.). *Elec. J. Pl. Breed.*, **2**(3): 372-376 (2011).
4. Fonseca, S. and Patterson, F.L., Hybrid vigour in a seven parent's diallel cross in common winter wheat (*T. aestivum* L.). *Crop Sci.*, **8**: 85-88 (1968).
5. Golakia, P.R., Madaria, R.B., Kavani, R.H. and Mehta, D.R., Gene effects, heterosis and inbreeding depression in castor, *Ricinus communis* L. *J. Oilseeds Res.*, **21**(2): 270-273 (2004).
6. Gopani, D.D., Kabaria, M.M. and Patel, R.H., Studies of hybrid vigour in castor. *Indian J. Agric. Sci.*, **38**(3): 520-527 (1968).
7. Joshi, H.J., Mehta, D.R. and Jadon, B.S., Heterosis for seed yield and its components in castor hybrids. *Indian J. Agric. Res.*, **36**(4): 264-268 (2002a).
8. Lavanya, C. and Chandramohan, Y., Combining ability and heterosis for seed yield and yield components in castor. *J. Oilseeds Res.*, **20**(2): 220-224 (2003).
9. Makani, A.Y., Patel, M.P., Patel, P.S., Patel, P.C. and Pandya, M.M., Heterosis for seed yield, its components and wilt resistance over environments in castor (*Ricinus communis* L.). *Int. J. Agril. Sci. Res.*, **5**(6): 313-320 (2015).
10. Manivel, P., Hussain, H.S.J., Dharmalingam, V. and Pandian, I. S. 1999. Heterosis for yield and its components over environments in castor (*Ricinus communis* L.). *Madras Agric. J.*, **86**(1-3): 65-68.
11. Mehta, D.R., Vashi, P.S. and Kukadia, M.U., Hybrid vigour in castor. *GAU Res. J.*, **17**(1): 16-22 (1991).
12. Meredith, W.R. and Bridge, R.R., Heterosis and gene action in cotton, *G. hirsutum* L. *Crop Sci.*, **12**: 304-310 (1972).
13. Panse, V.G. and Sukhatme, P.V., *Statistical Methods for Agricultural Workers*. Indian Council of Agricultural Research, New Delhi (1985).
14. Patel, A. R., Patel, K.V. and Patel, J.A., Extent of heterotic effects for seed yield and component characters in castor (*Ricinus communis* L.) under semi rabi condition. *Indian J. Agric. Res.*, **47**(4): 368-372 (2013).
15. Patel, J.B. and Pathak, H.C., Heterosis for seed yield per plant and its components in

- castor (*Ricinus communis* L.). *J. Oilseeds Res.*, **23(1)**: 93-95 (2006).
16. Patted, V.S., Shankergoud, I. and Prabhakaran, A. J., Heterosis for yield and yield attributing traits in castor (*Ricinus communis* L.). *Adv. Life Sci.*, **5(9)**: 3613-3218 (2016).
17. Ramana, P.V., Lavanya, C. and Ratnasree, P., Combining ability and heterosis studies under rainfed conditions in castor (*Ricinus communis* L.). *J. Oilseeds Res.*, **65(4)**: 325-326 (2005).
18. Rana, M., Dhamija, H., Prashar, B. and Sharma, S., *Ricinus communis* L. A review. *Int. J. Pharm. Tech. Res.*, **4(4)**: 1706-1711 (2012).
19. Saiyed, M.P., Shukla, P.T. and Dhameliya, H.R., Heterosis for yield and yield components in castor (*Ricinus communis* L.) over environments. *GAU Res. J.*, **23(1)**: 22-27 (1997).
20. Sapovadiya, M.H., Dobariya, K.L., Babariya, C.A., Mungra, K.S. and Vavdiya, P. A., Heterosis for seed yield and its components over environments in castor (*Ricinus communis* L.). *Elec. J. Pl. Breed.*, **6(4)**: 1118-1123 (2015).
21. Sridhar, V., Dangi, K.S., Reddy, A.V., Sudhakar, R. and Sankar, A.S., Heterosis for seed yield and yield components in castor (*Ricinus communis* L.). *Int. J. Agric. Bio.*, **2(1)**: 64-67 (2009).
22. Thakkar, D.A., Jadon, B.S., Patel, K.M. and Patel, C.J., Heterosis over environments for seed yield and other attributes in castor (*Ricinus communis* L.). *J. Oilseeds Res.*, **22(2)**: 324-326 (2005).
23. Weiss, E.A., *Oilseed Crops*, Oxford, Blackwell Science. pp. 364 (2000).