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Combining ability analysis for seed yield per plant and its components in castor (*Ricinus communis* L.)

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Abstract
Combining ability for seed yield and its component traits in castor was studied using line x tester mating design involving four diverse pistillate testers (Females) and eighteen inbred lines (males). Analysis of variance revealed that the estimates of σ^2GCA were higher than the corresponding σ^2SCA for days to flowering of primary raceme, plant height up to primary raceme, oil content, indicated that the preponderance of additive component of genetic variance for these traits, while for the remaining traits, non-additive component of genetic variance was predominant. Three females JP 96, JP 106 and SKP 84 and six males JI 244, SKI 215, SKI 327, SKI 392, SKI 405 and 500-2 exhibited good general combining ability effect for seed yield. The best three hybrids on the basis of significant positive SCA effect for seed yield per plant were JP 106 x JI 390 (good x average combiners), JP 96 x SKI 392 (good x good combiners) and SKP 84 x JI 244 (good x good combiners). The top high yielding hybrids JP 96 × SKI 392 (good x good combiners), JP 96 × SKI 215 (good x good combiners) and SKP 84 × JI 244 (good x good combiners), with significant heterobltiosis as well as standard heterosis, also depicted significant sca effect for seed yield per plant.

Keywords: combining ability, GCA, SCA, gene action

Introduction
Castor (*Ricinus communis* L.) is an important non-edible oilseed crop of India. Castor has chromosomes 2n=20 and belongs to monospecific genus *Ricinus* of *Ephorbiaceae* family. It has cross pollination up to the extent of 50 per cent. Because of its hardiness, castor plays an important role in the economy of arid and semi-arid regions of the country. Castor seed contains 48 to 56 per cent oil of tremendous industrial value and is mainly utilized in the production of soaps, refined and perfumed hair oil, printing inks, varnishes, synthetic resins, carbon paper, lubricant, ointments, other cosmetics and processed leather etc. The refined oil also has a good domestic market. Castor oil is the source of sebacic acid which is used in the manufacture of nylon and vinyl resins (Nagraj, 1996) [14].

In genetic improvement, the choice of appropriate parents to be incorporated in hybridization programme is very crucial step for breeders, particularly if the aim is improvement of complex quantitative characters, such as seed yield and its components. For this, it is always essential to evaluate available promising lines in their hybrid combinations for yield and yield contributing characters (Giriraj *et al.*, 1973) [6]. The use of parents of known superior genetic worth ensures much better success. Some idea may be obtained from their *per se* performance, particularly for yield contributing characters. However, proper information on magnitude of heterosis, combining ability and gene action for seed yield per plant and its component characters involved in the inheritance of different parents and their crosses would be more helpful to plant breeders in selecting the elite parents and desirable cross combinations for commercial exploitation of hybrid vigour and also in formulating the efficient breeding programme for the improvement of seed yield and its components (Dangaria *et al.*, 1987) [5].

Materials and Methods
Experimental material consisting of 95 entries comprised of four pistillate lines (JP 96, JP 106, SKP 84 and VP 1, used as testers/females) and ten inbred lines (JI 244, JI 390, JI 398, JI 424, JI 426, JI 436, JI 437, SKI 215, SKI 327, SKI 343, SKI 392, SKI 397, SKI 405, RG 3041, RG 3073, JC 24, PCS 124 and 500-2 used as lines/males) and their 72 hybrids developed through line x tester mating design along with standard check hybrid (GCH 9) were evaluated in a randomized block design with three replications. The materials were evaluated during *kharif* 2017-18 at the Main Oilseeds Research Station, 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. Analysis of variance for combining ability was computed according to the model given by Kempthorne (1957) [9], which is analogous to design II of Comstock and Robinson (1952) in terms of covariance of half-sibs (H.S.) and full-sibs (F.S.).

Results and Discussion

The partitioning of variances due to the crosses (Table 1) showed that the mean squares due to females, males and females x males were found significant for all the characters except for the mean squares due to male and females x males for oil content. Mean squares due to females and males were found significant when tested against the interaction variance for all the characters except for number of capsules on primary raceme in case of females and days to maturity of primary raceme and number of effective branches per plant for males. These results indicated that both additive and non-additive genetic variances played a vital role in the inheritance of all these traits. The present results are in accordance with the findings of Madariya *et al.* (2008) [11], Patel *et al*, (2008) [16], Barad *et al.* (2009) [2], Ramesh *et al.* (2013) [21], Aher *et al.* (2014) [1], Chaudhari and Patel (2014) [4], Golakia *et al.* (2015) [7], Patel *et al.* (2015) [17], Rajani *et al.* (2015) [20], Patel *et al.* (2016) [18] and Punewar *et al.* (2017) [19].

The estimated variances due to females (σ^2f) were higher than the corresponding variances due to males (σ^2m) for days to flowering of primary raceme, days to maturity of primary raceme, effective branches per plant, seed yield per plant and oil content whereas, for plant height up to primary raceme, number of nodes up to primary raceme, length of primary raceme, effective length of primary raceme, number of capsules on primary raceme, shelling out turn and 100-seed weight, the variances due to males (σ^2m) were higher than those due to females (σ^2f). The estimates of σ^2GCA were higher than the corresponding σ^2SCA for days to flowering of primary raceme, plant height up to primary raceme and oil content whereas for the remaining characters estimates of σ^2SCA were higher than the corresponding σ^2GCA.Thus, the ratio of σ^2GCA/σ^2SCA was more than unity for days to flowering of primary raceme and plant height up to primary raceme, thereby suggesting the presence of additive gene action for the control of these characters. The predominance of additive gene action for these traits has been reported by Saiyed *et al.* (1993) [22], Chakrabarty (1997) [3], Madariya *et al.* (2008) [11], Barad *et al.* (2009) [2], Patel *et al*. (2016) [18], Jalu *et al*. (2017) [8]. Per cent contribution of variances due to females, males and females x males interaction (Table 1) revealed that the females contributed higher towards variance for days to flowering of primary raceme. Males contributed higher towards variance for plant height up to primary raceme, number of nodes up to primary raceme, length of primary raceme, effective length of primary raceme, 100-seed weight, seed yield per plant and oil content. Females x males contributed higher towards variance for days to maturity of primary raceme, number of effective branches per plant, number of capsules on primary raceme and shelling out turn.

Looking to the significance of both types of gene actions in the expression of different characters under study, it is suggested that biparental matings with reciprocal recurrent selection should be employed so that additive as well as non-additive gene action could be exploited simultaneously for population improvement. However, in view of the preponderance of non-additive gene action and high heterosis observed for seed yield and yield attributing characters, it is suggested that heterosis breeding could profitably be used for exploitation of hybrid vigour in castor on commercial scale.

Among the parents, three females *viz.*, JP 96, JP 106 and SKP 84 and six males *viz.*, JI 244, SKI 215, SKI 327, SKI 392, SKI 405 and 500-2 exhibited good general combining ability effect for seed yield per plant. Among the pistillate lines, JP 96 was found good general combiner for days to maturity of primary raceme, 100-seed weight, seed yield per plant and number of effective branches per plant; JP 106 was found good general combiner for length of primary raceme, effective length of primary raceme, number of effective branches per plant, number of capsules on primary raceme, seed yield per plant and oil content; SKP 84 was found good general combiner for length of primary raceme, number of capsules on primary raceme, shelling out turn, 100-seed weight and seed yield per plant and VP 1 was found good general combiner 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. Thus, the association between *per se* performance of parents and their gca effect suggested that while selecting the parents for hybridization programme, *per se* performance of the parents should also be given due consideration. Thus, if a character is uni-directionally controlled by a set of alleles and additive effects are important, the choice of parents on the basis of *per se* performance may be more effective. Similar findings have also been reported by Dangaria *et al.* (1987) [5], Mehta *et al.* (1991) [13], Patel (1994) [15], Sudhakar *et al.* (1995) [23], Mehta (2000) [12], Lavanya and Chandramohan (2003) [10], Tank *et al.* (2003) [24] and Golakia *et al.* (2015) [7]. However, this cannot be taken as a rule because genotypes with high *per se* performance need not always be good general combiners.

Likewise, among the male parents, JI 244 was found good general combiner for number of capsules on primary raceme, 100-seed weight and seed yield per plant; JI 390 for days to flowering of primary raceme, number of nodes up to primary raceme, number of effective branches per plant, 100-seed weight and seed yield per plant; JI 398 for plant height up to primary raceme, number of nodes up to primary raceme, length of primary raceme, effective length of primary raceme, shelling out turn and 100-seed weight; JI 424 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 and shelling out turn; JI 436 for days to maturity of primary raceme, plant height up to primary raceme, number of nodes up to primary raceme, length of primary raceme, number of capsules on primary raceme and 100-seed weight; SKI 215 for length of primary raceme, effective length of primary raceme, number of effective branches per plant, number of capsules on primary raceme, shelling out turn and seed yield per plant; SKI 327 for length of primary raceme, effective length of primary raceme, number of capsules on primary raceme and seed yield per plant; SKI 343 for days to flowering of primary raceme, days to maturity of primary raceme, effective length of primary raceme, number of capsules on primary raceme and 100 seed weight; SKI 392 for length of primary raceme, effective length of primary raceme, number of effective branches, number of capsules on primary raceme and seed yield per plant; SKI 397 for days to maturity of primary raceme, number of nodes up to primary raceme, length of primary raceme, effective length of primary raceme and number of capsules on primary raceme; SKI 405 for number of capsules on primary raceme, shelling out turn and seed yield per plant; RG 3041 for length of primary raceme, effective length of primary raceme, number of capsules on primary raceme and 100-seed weight; RG 3073 for plant height up to primary raceme; PCS 124 for plant height up to primary raceme and number of nodes up to primary raceme; JC 24 for shelling out turn and 500-2 for number of effective branches per plant, seed yield per plant and oil content. The parents identified as good general combiners simultaneously for more number of characters can be considered as the potential parents and should be preferred in breeding programme in order to combine more number of characters by involving fewer number of parents in crossing programme. It is suggested that population involving these parents in a multiple crossing programme may be developed for isolating desirable recombinants. Further, the varieties or lines showing good general combining ability for particular component may also be utilized in component breeding programme for effective improvement in particular components, ultimately seeking improvement in seed yield itself.

The estimates of sca effects revealed (Table 3A and 3B) that none of the crosses was consistently superior for all the traits. Out of 72 hybrids studied, 20 cross combinations exhibited significant and positive sca effect for seed yield per plant. The highest yielding hybrid JP 96 × SKI 392 had also registered positive sca effect for seed yield per plant involved good x good general combiners for seed yield per plant. Likewise, the cross JP 96 × SKI 215 depicted significantly the highest and desirable sca effect for seed yield per plant, which involved good x good general combining parents for seed yield per plant, The third high yielding cross, SKP 84 × JI 244 involved good x good combiners for seed yield per plant, also exhibited positive sca effect (Table 3B).

Estimation of sca effect did not revealed any specific trend among the crosses. The crosses exhibited high sca effect did not always involve both parents as good general combiners with high gca effect, thereby suggesting importance of intra as well as inter-allelic interactions. The high sca effect of crosses in general correspond to their high heterotic effects, but these might also be accompanied by poor and /or average gca effect of their parents. The crosses having high sca effect for seed yield per plant had also registered significant sca effect in desirable direction for some of the yield component characters. Out of ten top most high yielding cross combinations, six cross combinations *viz*., JP 106 × SKI 215, JP 106× SKI 405, JP 106 × SKI 327, SKP 84 × 500-2, JP 96 × JC 24 and JP-96 × SKI 397 also manifested high and desirable sca effect for seed yield per plant (Table 3A&3B), which involved either good x good or good x average general combiners.

The best cross combination SKP 84 x JI 437 involved the parents with good x good general combiners followed by JP 96 x JI 244 and JP 106 x PCS 124 exhibited significant and negative sca effect for days to flowering of primary raceme, were considered as good cross combinations for exploiting earliness. Similarly, JP 106 x SKI 405, JP 106 x PCS 124 and JP 106 x SKI 397 for days to maturity of primary raceme; SKP 84 x SKI 343, VP 1 x JI 426 and JP 96 x SKI 405 for plant height up to primary raceme; JP 96 x JI 390, SKP 84 x SKI 343 and JP 106 x SKI 397 for number of nodes up to primary raceme; JP 106 x JI 436, VP 1 x JI 244 and JP 96 x SKI 397 for length of primary raceme; JP 106 x JI 436, VP 1 x JI 424 and JP 106 x JI 437 for effective length of primary raceme; JP 106 x JI 390, JP 96 x RG 3073 and JP 106 x SKI 215 for number of effective branches per plant; VP 1 x JI 390, SKP 84 x JI 436 and JP 106 x SKI 215 for number of capsules on primary raceme; JP 106 x JI 390, JP 96 x JI 398 and SKP 84 x RG 3041 for shelling out turn and JP 96 x JI 244, SKP 84 x JI 437 and SKP 84 x JI 390 for 100-seed weight, exhibited significant sca effect in desired direction and thus, were considered best specific combiners for the respective traits (Table 3A & 3B).

Table 1: Analysis of variance for combining ability 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)
Females	3	1883.26 **++	3116.14 **++	6631.19 **++	51.25 **++	1260.67 **++	1078.18 **++
Males	17	109.72 **+	327.75 **	1567.57 **++	22.34 **++	780.09 **++	749.10 **++
Females *x* Males	51	58.72 **	386.71 **	266.31 **	5.63 **	135.08 **	135.17 **
Error	142	6.63	13.80	14.48	0.80	17.91	11.14
Variance components							
σ 2f		34.75	57.45	122.53	0.93	23.01	19.76
σ 2m		8.59	26.16	129.42	1.79	63.51	61.49
σ 2fm		17.26	124.30	83.94	1.61	39.05	41.34
σ 2GCA		29.99	51.76	123.78	1.09	30.37	27.34
σ 2SCA		17.26	124.30	83.94	1.61	39.05	41.34
σ 2GCA/σ 2SCA		1.73	0.41	1.47	0.67	0.77	0.66
Per cent contribution							
Females		58.83	26.98	33.08	18.73	15.80	14.14
Males		17.77	16.08	44.32	46.22	55.41	55.70
Females *x* Males		28.39	56.93	22.59	34.99	28.78	30.15

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

+, ++ Significant at 5 and 1 % levels, respectively against lines x testers interaction

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 (%)
Females	3	33.00**++	1413.72**	469.12**++	352.30 **++	96482.52 **++	2.92 **++
Males	17	5.01**	2152.76**++	130.99**+	95.99 **++	20193.32 **++	0.90 ++
Females *x* Males	51	4.79**	740.28**	58.54**	22.72 **	6373.09 **	0.28
Error	142	0.62	42.49	2.00	0.83	213.13	0.59
Variance components							
σ 2f		0.59	25.39	8.65	6.50	1782.76	0.04
σ 2m		0.36	175.85	10.74	7.92	1665.01	0.02
σ 2fm		1.39	232.59	18.84	7.29	2053.32	-0.10
σ 2GCA		0.55	52.74	9.03	6.76	1761.35	0.04
σ 2SCA		1.39	232.59	18.84	7.29	2053.32	-0.10
σ 2GCA/σ 2SCA		0.39	0.22	0.47	0.92	0.85	-0.4
Per cent contribution							
Females		23.08	5.39	21.25	27.46	30.22	22.72
Males		19.88	46.56	33.63	42.41	35.84	39.72
Females *x* Males		57.03	48.03	45.10	30.11	33.93	37.55

*, ** Significant at 5 and 1 % levels, respectively
+, ++ Significant at 5 and 1 % levels, respectively against lines x testers interaction

Table 2: Estimation of general combining ability (gca) effect for different character in castor

S. No.	Parents	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)
	Females						
1	JP-96	2.51*	-2.91*	6.48**	-0.13	0.01	-0.24
2	JP-106	4.81**	8.94**	4.73*	0.28	4.94*	5.15**
3	SKP-84	1.25*	2.75*	5.36**	1.09*	1.60*	0.80
4	VP-1	-8.57**	-8.78**	-16.58**	-1.24**	-6.56**	-5.71**
	SE(g_i)±	0.49	0.71	0.73	0.17	0.81	0.64
	Males		;lk0				
1	JI-244	-1.54	-0.18	-2.63	-0.35	-2.45	-3.62*
2	JI-390	-3.87*	0.15	4.15*	-1.60**	-3.55	-4.60*
3	JI-398	-1.62	2.40	-7.34**	-1.33*	6.07*	6.02**
4	JI-424	-6.37**	-5.09*	-18.94**	-2.82**	-15.20**	-14.98**
5	JI-426	0.79	0.73	12.33**	-0.30	-3.25	-3.70*
6	JI-436	-1.37	-4.26*	-7.73**	-1.52**	4.26*	2.52
7	JI-437	5.04**	-2.51	2.06	0.27	-2.28	-2.45
8	SKI-215	4.45**	15.90**	15.93**	1.24*	9.04**	8.79**
9	SKI-327	1.70	1.06	6.03**	1.27*	3.76*	5.96**
10	SKI-343	-3.29*	-8.09**	0.33	-0.47	1.47	3.06*
11	SKI-392	3.45*	4.31*	9.18**	1.26*	18.27**	16.79**
12	SKI-397	-0.04	-4.09*	-1.49	-1.35**	4.27*	4.72*
13	SKI-405	-0.95	-0.93	4.36*	1.49**	-0.77	-1.17
14	RG-3041	3.37*	-2.68	19.01**	2.44**	7.84**	8.67**
15	RG-3073	-0.62	2.81	-25.76**	-0.07	-11.23**	-10.75**
16	JC-24	-1.12	5.06*	0.93	0.06	-6.15*	-5.53**
17	PCS-124	-0.62	-2.09	-11.93**	0.75*	-10.36**	-9.48**
18	500-2	2.62*	-2.51	1.48	1.04*	0.26	-0.25
	SE(g_i)±	1.05	1.51	1.55	0.36	1.72	1.36

Table 2: Conti…

Sr. No.	Parents	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 (%)
Females							
1	JP-96	0.66*	-6.70*	-1.57*	1.66**	22.90**	-0.03
2	JP-106	0.47*	2.90*	-2.55**	0.32	10.48*	0.33*
3	SKP-84	-0.06	4.98*	4.13**	1.71**	28.96**	-0.09
4	VP-1	-1.07**	-1.09	0.00	-3.70**	-62.34**	-0.20
	SE(g_i)±	0.15	1.25	0.27	0.17	2.80	0.14
Males							
1	JI-244	-0.87*	14.02**	0.17	6.18**	16.82*	0.22
2	JI-390	0.74*	-10.82**	5.25**	2.34**	-11.67	0.03
3	JI-398	-0.36	5.22	3.34**	4.59**	-15.08*	-0.17

4	JI-424	-0.50	-10.09**	4.34**	0.01	-25.28**	-0.41
5	JI-426	0.37	-5.29*	-0.32	0.01	-8.20	0.13
6	JI-436	-0.19	23.94**	-6.24**	2.43**	-45.77**	-0.43
7	JI-437	-0.82*	-15.04**	-0.40	-2.48**	-54.07**	-0.10
8	SKI-215	1.39**	10.81**	3.42**	0.01	71.22**	0.02
9	SKI-327	-0.47	5.47*	-0.40	-4.98**	12.22*	0.00
10	SKI-343	-0.63*	4.56*	0.42	1.59**	-23.00**	-0.25
11	SKI-392	0.09	13.42**	-2.32**	-0.31	91.46**	-0.12
12	SKI-397	-0.61	12.21**	-0.07	-1.56**	8.36	0.21
13	SKI-405	0.44	7.67*	2.75**	-3.56**	49.42**	0.19
14	RG-3041	0.62	8.91*	-5.49**	1.26*	-28.73**	-0.00
15	RG-3073	-0.33	-18.87**	-1.49*	-2.48**	-65.97**	-0.24
16	JC-24	-0.06	-21.79**	1.34*	0.18	0.27	-0.02
17	PCS-124	0.34	-15.02**	-5.32**	-2.90**	9.89	0.23
18	500-2	0.88*	-9.34*	1.00	-0.31	18.11*	0.72*
	SE(g_i)±	0.32	2.66	0.57	0.37	5.96	0.31

Table 3A: Estimates of specific combining ability (sca) effect 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, length of primary raceme and effective length of primary raceme in castor

S. No.	Crosses	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)
1	JP-96 × JI 244	-7.68**	-4.83*	5.44*	0.55	-16.00**	-16.00**
2	JP-96 × JI 390	-3.68*	-7.83**	-10.93**	-2.92**	-11.43**	-10.08**
3	JP-96 × JI 398	-5.93**	4.91*	7.76**	-0.12	-2.73	-5.85**
4	JP-96 × JI 424	-2.84	-13.92**	-6.90**	-1.71**	-7.91**	-6.10**
5	JP-96 × JI 426	5.98**	4.91*	2.14	1.17*	-2.46	-2.32
6	JP-96 × JI 436	-4.51**	-8.08**	-9.85**	0.52	-6.38**	-3.01
7	JP-96 × JI 437	0.40	-6.17**	2.94	0.72	2.90	3.49
8	JP-96 × SKI 215	3.65*	6.07**	-5.32*	1.22*	5.16*	2.17
9	JP-96 × SKI 327	-3.93**	-8.75**	-2.88	-0.87	3.91	2.61
10	JP-96 × SKI 343	7.06**	4.07	23.81**	1.47**	0.86	5.11**
11	JP-96 × SKI 392	-1.01	-13.00**	4.56*	0.47	0.20	1.37
12	JP-96 × SKI 397	2.48	8.41**	-1.15	1.75**	8.80**	7.64**
13	JP-96 × SKI 405	3.40*	23.91**	-12.75**	0.17	4.45	4.87*
14	JP-96 × RG-3041	2.06	-4.33*	-7.80**	-0.44	2.43	1.56
15	JP-96 × RG-3073	3.73*	13.82**	8.71**	0.67	7.45**	8.12**
16	JP-96 × JC-24	3.23*	14.24**	3.94	-1.92**	2.43	1.17
17	JP-96 × PCS-124	-2.59	-5.25*	-5.91**	-0.68	3.30	1.79
18	JP-96 × 500-2	0.15	-8.17**	4.19	-0.04	5.01*	3.42
19	JP-106 × JI 244	1.35	10.31**	-2.99	1.39**	6.80**	6.46**
20	JP-106× JI 390	3.35*	-0.02	-6.18**	1.98**	5.04*	5.37**
21	JP-106× JI 398	6.77**	-5.27*	-12.68**	-0.08	5.80*	4.41*
22	JP-106× JI 424	-2.14	13.22**	7.58**	-1.20*	3.02	-0.30
23	JP-106× JI 426	1.69	9.39**	17.83**	-0.85	1.00	0.21
24.	JP-106× JI 436	4.19**	13.72**	12.36**	1.29*	10.95**	11.12**
25.	JP-106× JI 437	-0.89	15.64**	-7.43**	0.76	3.64	9.96**
26.	JP-106× SKI 215	-0.97	-0.44	8.56**	-0.67	-3.76	-4.15*
27.	JP-106× SKI 327	0.44	-4.94*	2.26	-0.37	-2.87	-4.25*
28.	JP-106× SKI 343	-5.22**	-1.77	-5.56*	0.78	-1.59	-3.28
29.	JP-106× SKI 392	2.02	5.81**	-5.94**	0.58	-7.59**	-5.55**
30.	JP-106× SKI 397	-1.14	-15.44**	3.20	-2.20**	-3.12	-2.55
31.	JP-106× SKI 405	-1.56	-18.60**	1.80	0.21	8.79**	6.61**
32.	JP-106× RG-3041	-0.56	13.47**	14.81**	-1.73**	-6.82**	-7.63**
33.	JP-106× RG-3073	1.10	-12.02**	-10.86**	0.04	-8.27**	-7.67**
34.	JP-106× JC-24	0.94	5.06*	-0.49	0.84	7.10**	8.37**
35.	JP-106× PCS-124	-7.22**	-16.77**	-5.89**	0.15	-7.88**	-5.27**
36.	JP-106 × 500-2	-2.14	-11.35**	-10.38**	-0.93	-10.24**	-11.83**
37.	SKP-84 × JI 244	4.91**	-6.83**	-1.23	-0.67	-1.51	0.74

Table 3A: Contd…

Sr. No.	Crosses	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)
38.	SKP-84 × JI 390	-0.75	12.82**	16.51**	1.57**	5.05*	4.59*
39.	SKP-84 × JI 398	0.66	0.57	1.35	1.37**	-1.11	1.29
40.	SKP-84 × JI 424	0.07	-6.92**	-5.11*	2.85**	-2.76	-4.68*

41.	SKP-84 × JI 426	-5.75**	-12.75**	-6.53**	0.60	5.68*	3.03
42.	SKP-84 × JI 436	-0.58	-8.42**	-1.86	-1.11*	-1.56	-4.42*
43.	SKP-84 × JI 437	-8.67**	-7.17**	8.80**	-0.44	-4.41	-6.88**
44.	SKP-84 × SKI 215	1.57	-4.58*	8.13**	0.18	-4.28	-0.20
45.	SKP-84 × SKI 327	3.32*	14.57**	1.30	0.68	0.60	1.89
46.	SKP-84 × SKI 343	-2.67	-4.25*	-18.53**	-2.76**	-5.78*	-4.66*
47.	SKP-84 × SKI 392	4.91**	14.32	4.08	0.10	4.68	3.99*
48.	SKP-84 × SKI 397	0.07	4.74*	1.16	-0.21	0.28	1.93
49.	SKP-84 × SKI 405	-4.67**	-10.08**	-3.70	-1.06*	-5.60*	-6.56**
50.	SKP-84 × RG-3041	2.99*	-9.33**	-5.88**	1.12*	-0.68	-0.55
51.	SKP-84 × RG-3073	-3.00*	10.49**	1.43	0.23	6.13*	6.28**
52.	SKP-84 × JC-24	-2.50	-14.08**	1.66	-0.96	0.91	0.79
53.	SKP-84 × PCS-124	8.32**	9.07**	-0.15	-0.55	1.42	0.41
54.	SKP-84 × 500-2	1.74	17.82**	-1.41	-0.94	2.96	2.98
55.	VP-1 × JI 244	1.41	1.36	-1.21	-1.27*	10.71**	8.79**
56.	VP-1 × JI 390	1.07	-4.96*	0.60	-0.62	1.34	0.11
57.	VP-1 × JI 398	-1.50	-0.21	3.57	-1.15*	-1.95	0.14
58.	VP-1 × JI 424	4.91**	7.61**	4.43*	0.06	7.66**	11.09**
59.	VP-1 × JI 426	-1.92	-1.55	-13.44**	-0.92	-4.22	-0.92
60.	VP-1 × JI 436	0.91	2.78	-0.64	-0.70	-3.00	-3.68
61.	VP-1 × JI 437	9.16**	-2.30	-4.31	-1.04*	-2.12	-6.57**
62.	VP-1 × SKI 215	-4.25**	-1.05	-11.38**	-0.74	2.87	2.17
63.	VP-1 × SKI 327	0.16	-0.88	-0.68	0.56	-1.63	-0.25
64.	VP-1 × SKI 343	0.82	1.94	0.28	0.51	6.51**	2.84
65.	VP-1 × SKI 392	-5.92**	-7.13**	-2.69	-1.15*	2.71	0.17
66.	VP-1 × SKI 397	-1.42	2.28	-3.21	0.66	-5.95*	-7.02**
67.	VP-1 × SKI 405	2.82	4.78*	14.65**	0.67	-7.63**	-4.92*
68.	VP-1 × RG-3041	-4.50**	0.19	-1.13	1.06*	5.07*	6.62**
69.	VP-1 × RG-3073	-1.83	-12.30**	0.72	-0.95	-5.30*	-6.73**
70.	VP-1 × JC-24	-1.67	-5.21*	-5.11*	2.04**	-10.45**	-10.35**
71.	VP-1 × PCS-124	1.49	12.94**	11.96**	1.08*	3.15	3.06
72.	VP-1 × 500-2	0.24	1.69	7.60**	1.92**	2.26	5.42**
SE(s_{ij}) ±		1.48	2.14	2.19	0.51	2.44	1.92

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

Table 3B: Estimates of specific combining ability (sca) effect for number of effective branches per plant, number of capsules on primary raceme, shelling out turn, 100 seed weight, seed yield per plant, oil content in castor

S. No.	Crosses	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 (%)
1.	JP-96 × JI 244	0.77	-10.03**	-0.84	5.83**	-16.68*	-0.30
2.	JP-96 × JI 390	-1.43**	-19.78**	-1.25	-2.99**	-33.05**	-0.12
3.	JP-96 × JI 398	0.23	8.30*	8.99**	-0.91	-0.37	0.03
4.	JP-96 × JI 424	-0.69	2.55	0.65	-0.66	-55.57**	-0.16
5.	JP-96 × JI 426	-1.07*	-0.31	2.65**	0.67	-6.98	0.44
6.	JP-96 × JI 436	-0.23	-18.01**	1.57	0.25	-33.68**	0.01
7.	JP-96 × JI 437	-1.80**	14.56**	-2.25**	-0.82	-15.12	0.02
8.	JP-96 × SKI 215	-0.08	12.91**	1.24	2.67**	38.64**	0.06
9.	JP-96 × SKI 327	-0.42	-11.94**	3.07**	0.00	-21.21*	0.26
10.	JP-96 × SKI 343	0.57	-1.29	-3.09**	4.08**	-71.12**	-0.08
11.	JP-96 × SKI 392	0.80	-7.29	3.32**	-0.32	83.34**	-0.24
12.	JP-96 × SKI 397	0.22	5.65	-5.92**	0.25	54.97**	0.36
13.	JP-96 × SKI 405	-0.53	15.25**	1.57	-1.07*	-6.68	0.17
14.	JP-96 × RG-3041	-0.22	11.48**	1.49	-4.57**	22.21**	0.24
15.	JP-96 × RG-3073	2.33**	20.33**	-4.50**	-0.82	26.57**	0.14
16.	JP-96 × JC-24	0.26	-13.61**	-0.67	-1.49**	64.06**	-0.25
17.	JP-96 × PCS-124	-0.37	9.21*	-2.67**	0.25	-45.35**	-0.36
18.	JP-96 × 500-2	1.68**	-17.99**	-3.34**	-0.32	16.02	-0.25
19.	JP-106 × JI 244	1.09*	6.69	-2.52**	0.17	-71.26**	0.07
20.	JP-106× JI 390	4.01**	-13.05**	9.05**	-0.66	86.16**	0.29
21.	JP-106× JI 398	-0.34	-8.44*	-3.02**	-3.24**	9.38	0.17
22.	JP-106× JI 424	0.85	-15.32**	-0.02	-1.99**	22.05**	-0.14
23.	JP-106× JI 426	1.51**	-13.52**	2.97**	0.67	-7.03	-0.18
24	JP-106× JI 436	-0.18	-4.09	4.55**	1.25*	15.26	0.05
25	JP-106× JI 437	0.21	11.82**	2.72**	-3.49**	-10.03	-0.24
26	JP-106× SKI 215	1.96**	25.70**	1.55	-3.99**	39.46**	-0.14
27	JP-106× SKI 327	0.06	-0.02	-0.94	1.67**	70.07**	-0.07
28	JP-106× SKI 343	-2.21**	19.09**	-0.11	-0.24	1.70	-0.01
29	JP-106× SKI 392	-0.01	-0.64	-12.02**	1.00	-61.63*	0.29

30	JP-106× SKI 397	0.07	5.50	4.72**	0.25	-76.86**	-0.09
31	JP-106× SKI 405	0.08	11.57**	-2.44**	1.92**	43.46**	-0.28
32	JP-106× RG-3041	-0.90*	-11.32**	-7.19**	3.08**	-69.96**	-0.05
33	JP-106× RG-3073	-2.87**	-12.27**	4.47**	0.50	-6.13	0.05
34	JP-106× JC-24	-1.25**	19.30**	-4.36**	0.50	-14.04	0.27
35	JP-106× PCS-124	-0.78	-18.72**	1.63*	3.58**	36.26**	-0.01
36	JP-106 × 500-2	-1.29**	-2.27	0.97	-0.99	-6.88	0.03
37	SKP-84 × JI 244	-1.12*	4.70	1.78*	-1.21*	82.45**	0.13

Table 3B: Contd….

S. No.	Crosses	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 (%)
38.	SKP-84 × JI 390	-0.47	3.02	-4.63**	4.94**	-57.37**	-0.12
39.	SKP-84 × JI 398	0.43	-16.49**	-4.04**	4.69**	11.97	-0.19
40.	SKP-84 × JI 424	-1.13*	0.35	-1.71*	1.28*	31.97**	0.17
41.	SKP-84 × JI 426	-0.27	-2.71	-6.71**	-0.71	-30.77**	0.04
42.	SKP-84 × JI 436	-0.11	27.99**	-0.79	-2.13**	12.72	0.03
43.	SKP-84 × JI 437	1.28**	-4.09	4.37**	5.11**	32.82**	0.33
44.	SKP-84 × SKI 215	-0.86	-19.87**	-3.46**	0.61	-4.74	0.20
45.	SKP-84 × SKI 327	-0.29	4.79	-1.63*	-4.38**	-51.86**	-0.89*
46.	SKP-84 × SKI 343	0.76	-20.49**	1.20	-4.30**	36.29**	0.10
47.	SKP-84 × SKI 392	-0.03	-0.49	2.62**	-2.38**	-18.31*	0.31
48.	SKP-84 × SKI 397	0.81	5.72	2.03*	-0.13	13.25	-0.60
49.	SKP-84 × SKI 405	-0.01	-18.01**	1.53	0.86	-51.41**	-0.26
50.	SKP-84 × RG-3041	0.53	8.35*	6.45**	-1.96**	2.82	0.30
51.	SKP-84 × RG-3073	0.79	16.20**	4.78**	-0.21	-29.61**	-0.22
52.	SKP-84 × JC-24	0.22	1.72	-0.04	-1.55**	-39.39**	0.05
53.	SKP-84 × PCS-124	-0.24	5.15	-1.71*	-1.80**	14.32	0.48
54.	SKP-84 × 500-2	-0.28	4.14	-0.04	3.28**	44.84**	0.10
55.	VP-1 × JI 244	-0.74	-1.36	1.58	-4.79**	5.49	0.09
56.	VP-1 × JI 390	-2.09**	29.81**	-3.16**	-1.29*	4.26	-0.04
57.	VP-1 × JI 398	-0.32	16.63**	-1.91*	-0.54	-20.98*	-0.01
58.	VP-1 × JI 424	0.97*	12.41**	1.08	1.37*	1.54	0.13
59.	VP-1 × JI 426	-0.16	16.54**	1.08	-0.62	44.79**	-0.30
60.	VP-1 × JI 436	0.53	-5.88	-5.33**	0.62	5.69	-0.10
61.	VP-1 × JI 437	0.30	-22.30**	-4.83**	-0.79	-7.67	-0.12
62.	VP-1 × SKI 215	-1.01*	-18.75**	0.66	0.70	-73.37**	-0.11
63.	VP-1 × SKI 327	0.65	7.18	-0.50	2.70**	3.00	0.70
64.	VP-1 × SKI 343	0.87	2.69	2.00.*	0.45	33.12**	-0.01
65.	VP-1 × SKI 392	-0.75	8.43*	6.08**	1.70**	-3.40	-0.36
66.	VP-1 × SKI 397	-1.10*	-16.88**	-0.83	-0.37	8.62	0.33
67.	VP-1 × SKI 405	0.46	-8.81*	-0.66	-1.70**	14.62	0.37
68.	VP-1 × RG-3041	0.58	-8.51*	-0.75	3.45**	44.92**	-0.50
69.	VP-1 × RG-3073	-0.25	-24.26**	-4.75**	0.54	9.16	0.02
70.	VP-1 × JC-24	0.76	-7.41	5.08**	2.54**	-10.62	-0.07
71.	VP-1 × PCS-124	1.40**	4.34	2.75**	-2.04**	-5.23	-0.11
72.	VP-1 × 500-2	-0.10	16.13**	2.41**	-1.95**	-53.98**	0.11
SE(s_{ij}) ±		0.45	3.76	0.81	0.52	8.42	0.44

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

Conclusion

From the studies on general combining ability in castor, it can be concluded that nine parent's *viz*., JP 96, JP 106 and SKP 84 among female parents and JI 244, SKI 215, SKI 327, SKI 392, SKI 405 and 500-2 among male parents, were good general combiners for seed yield per plant and some of its component traits. Therefore, these parents may be involved in building up desirable gene pool in castor. The top high yielding hybrids JP 96 × SKI 392 (good x good combiners), JP 96 × SKI 215 (good x good combiners) and SKP 84 × JI 244 (good x good combiners), with significant heterobltiosis as well as standard heterosis, also depicted significant sca effect for seed yield per plant.

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