Available online at www.ijpab.com

DOI: http://dx.doi.org/10.18782/2320-7051.3050

ISSN: 2320 – 7051

Int. J. Pure App. Biosci. **5 (4):** 261-273 (2017)

Research Article

International Journal of Pure & Applied Bioscience

OPEN ACCESS

Combining Ability Analysis for Seed Yield per Plant and Its Components in Castor (*Ricinus communis* L.)

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Received: 29.05.2017 | Revised: 8.06.2017 | Accepted: 10.06.2017

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 ten 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, days to maturity of primary raceme, plant height up to primary raceme, number of nodes up to primary raceme and number of capsules on primary raceme, 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. Four parental lines, SKP 106 and JP 96 among the females and JI 441 and JI 435 among the males, exhibited good general combining ability effects for seed yield per plant and important yield components. The best three hybrids on the basis of significant positive sca effects for seed yield per plant were JP 96 x JI 437 (good x average combiners), JP 104 x JI 434 (poor x poor combiners) and SKP 84 x JI 437 (average x average combiners). The top high yielding hybrids SKP 84 × JI 435 (average x good combiners), JI 96 x JI 437 (good x average combiners) and SKP 84 × JI 437 (average x average combiners), with significant heterobeltiosis as well as standard heterosis, also depicted significant sca effects for seed yield per plant.

Key words: *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[11].

Cite this article: Jalu, R.K., Patel, J.B., Patel C.K. and Paneliya, M.R., Combining Ability Analysis for Seed Yield per Plant and Its Components in Castor (*Ricinus communis* L.), *Int. J. Pure App. Biosci.* **5(4):** 261-273 (2017). doi: http://dx.doi.org/10.18782/2320-7051.3050

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[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[5].

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. Analysis of variance for combining ability was computed according to the model given by Kempthorne), which is analogous to design II of Comstock and Robinson[3] in terms of covariance of half-sibs (H.S.) and full-sibs (F.S.).

RESULTS AND DISCUSSION

The partitioning of variance among the crosses (Table 1) showed that mean squares due to females were found significant 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, number of effective branches per plant, number of capsules on primary raceme and 100 seed weight. Mean squares due to males were found significant for days to flowering of primary raceme, days to maturity of primary raceme and seed yield per plant**.** Mean squares due to females x males were found significant for plant height up to primary raceme, length of primary raceme, effective length of 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. These results indicated that both additive and non-additive genetic variances played a vital role in the inheritance of all these traits. The results are in accordance with the findings of Ramesh *et al*[15]., Aher *et al*[1]., Chaudhari and Patel[2], Golakia *et al*[7]., Patel *et al*[12]., Rajani *et al*[14]., and Patel *et al*[13].

The estimated variances due to lines ($\sigma^2 f$) were higher than the corresponding variances due to testers ($\sigma^2 m$) for all the characters, except number of effective branches per plant, shelling out turn, seed yield per plant, oil content. The estimates of σ^2gca were higher than the corresponding σ^2sca 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 number of capsules on primary raceme, 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. This was further supported by the the ratio of σ^2gca/σ^2sca was less than unity for length of primary raceme, effective length of primary raceme, number of effective branches per plant**, s**helling out turn, 100 seed weight, seed yield per plant and oil content, while for remaining character, it was more than unity. Therefore, the characters, length of primary raceme, effective length of primary raceme, number of effective branches per plant**, s**helling out turn, 100 seed weight, seed yield per plant and oil content, emphasized the utility of hybrid breeding approach to exploit existing heterosis in castor. The predominance of non-additive gene action for seed yield and its component traits were also reported by Ramesh *et al*[15]., Chaudhari and Patel[2], Patel *et al*[12]., and Patel *et al*[13].

Per cent contribution of variances due to females, males and females x males interaction (Table 1) revealed that females contributed higher variance for days to flowering of primary raceme (47.16 %), days to maturity of primary raceme (45.46 %)**,** plant height up to primary raceme (75.56 %), number of nodes up to primary raceme (48.49 %) and number of capsules on primary raceme (50.40 %) than that of variances of males and females x males interaction. Males variance had lower contribution as compared to females and females x males interaction variances in all characters. Females x males interaction variance had higher contribution than that of females and males variances for length of primary raceme (63.78 %), effective length of primary raceme (63.92 %), number of effective branches per plant (52.95 %), shelling out turn (67.51 %), 100 seed weight (45.95 %), seed yield per plant (44.64 %) and oil content (62.38 %).

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.

Four parental lines, SKP 106 and JP 96 among the females and JI 441 and JI 435 among the males, exhibited good general combining ability effect for seed yield per plant (Table 2). Among the pistillate lines, JP 96 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, shelling out turn, 100 seed weight, seed yield per plant and oil content; JP 104 was found good general combiner for days to flowering of primary raceme, days to maturity of primary raceme, plant height up to primary raceme, number of node up to primary raceme, number of effective branches per plant and 100 seed weight; SKP 84 was found good general combiner for plant height up to primary raceme; and SKP 106 was found good general combiner for plant height up to primary raceme, number of capsule on primary raceme, seed yield per plant and oil content (Table 2). Thus, the association between *per se* performance of parents and their gca effects 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*[5]., Mehta *et al*[10]., Sudhakar *et al*[16]., Lavanya and Chandramohan[9], Tank *et al*[17]., and Golakia *et al*[7]. However, this cannot be taken as a rule because genotypes with high *per se* performance need not always be good general combiners. This could be attributed due to the intra and/or inter-allelic interaction of genes concerned with the character modified by environmental factors[4].

Likewise, among the male parents, JI 431 was found good general combiner for days to maturity of primary raceme, number of nodes up to primary raceme, 100 seed weight and oil content; JI 432 for number of nodes up to primary raceme, length of primary raceme, shelling out turn and 100 seed weight; JI 433 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 oil content; JI 434 for oil content; JI 435 seed yield per plant and oil content; JI 437 for days to maturity of primary raceme, plant height up to primary raceme, number of node up to primary raceme, number of capsules on primary raceme and shelling out turn; JI 438 for plant height up to primary raceme, number of effective branches per plant and 100 seed weight; JI 439 for plant height up to primary raceme; JI 440 for shelling out turn; and JI 441 was found good general combiner for effective length of primary raceme, shelling out turn, 100 seed weight and seed yield per plant (Table 2). 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 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 40 hybrids studied, 11 cross combinations exhibited significant and positive sca effects for seed yield per plant. The highest yielding hybrid SKP 84 × JI 435 had also registered positive sca effect for seed yield per plant involved average x good general combiner parents for seed yield per plant. Likewise, the cross JP 96 × JI 437 depicted significantly the highest and desirable sca effect for seed yield per plant, which involved good x average general combining parents for seed yield per plant, The third high yielding cross, SKP 84 × JI 437 involved average x average poor combiners for seed yield per plant, also exhibited positive sca effect (Table 3B).

Estimation of sca effects did not revealed any specific trend among the crosses. The crosses exhibited high sca effects did not always involve both parents as good general combiners with high gca effects, thereby suggesting importance of intra as well as inter-allelic interactions. The high sca effects of crosses in general correspond to their high heterotic effects, but these might also be accompanied by poor and /or average gca effects of their parents. The crosses having high sca effects for seed yield per plant had also registered significant sca effects in desirable direction for some of the yield component characters Out of ten top most high yielding cross combinations, four cross combinations *viz*., SKP 106 × JI 432, SKP 106 × JI 438, JP 104 × JI 441 and SKP 84 × JI 431 also manifested the high and desirable sca effect for seed yield per plant (Table 3B), which involved good x average, good x average, poor x good and average x average general combiners, respectively.

The best cross combination JP 96 x JI 440 involved the parents with average x poor combiner parents followed by JP 104 x JI 433 and SKP 84 x JI 434 exhibited significant and negative sca effects, were considered as good cross combinations for exploiting earliness (Table 3A). Similarly, JP 104 x JI 431, SKP 106 x JI 438 and SKP 84 x JI 438 for days to maturity of primary raceme (Table 3A); JP 106 x JI 435, JP 96 x JI 434 and JP 96 x JI 433 for plant height up to primary raceme (Table 3A); SKP 106 x JI 435, JP 104 x JI 438 and JP 96 x JI 433 for number of nodes up to primary raceme (Table 3A); JP 96 x JI 435, JP 96 x JI 432 and SKP 106 x JI 434 for length of primary raceme (Table 3A); JP 96 x JI 435, JP 96 x JI 432 and SKP 106 x JI 439 for effective length of primary raceme (Table 3A). JP 96 x JI 432, JP 96 x JI 431 and SKP 106 x JI 438 for number of effective branches per plant (Table 3B); JP 96 x JI 440, JP 96 x JI 431 and JP 104 x JI 434 for number of capsules on primary raceme (Table 3B); SKP 106 x JI 434, JP 104 x JI 438 and SKP 106 x JI 431 for shelling out turn (Table 3B); SKP 106 x JI 438, SKP 106 x JI 431 and JP 96 x JI 437 for 100 seed weight (Table 3B); and SKP 84 x JI 437, JP 96 x JI 439 and SKP 84 x JI 440 for oil content (Table 3B), exhibited the significant sca effects in desired direction were considered best specific combiners for respective traits.

Table 1: Analysis of variance and variance components of combining ability and per cent contribution 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		180.98	**	392.42	**	1214.42	**++	29.44	**	376.40	++	382.22	+
males	9		36.31	**	121.17	**	34.69		3.72		106.57		133.60	
Females *x* males	27		10.42		11.53		32.06	**	2.23		136.20	**	154.14	**
Error	78		7.33		16.83		15.68		1.98		26.58		21.44	
Variance components														
	n_1	n_2												
σ^2_f	3	27	5.78	**	12.51	**	39.95	**	0.91		11.66	**	12.02	**
σ^2_m	9	27	2.41	**	8.69	**	1.58		0.14		6.65	**	9.34	**
σ^2_{fm}	27	78	1.02		-1.76	**	5.46	**	0.08		36.54	**	44.23	**
σ^2_{GCA}		27	4.82 (4)	**	11.42 (5)	**	28.98 (3)	**	0.69 (4)		10.23 (3)	**	11.26 (5)	**
σ^2_{SCA}	27	78	1.02		-1.76	**	5.46	**	0.08		36.54	**	44.23	**
$\sigma^2_{GCA}/\sigma^2_{SCA}$			2.41		-6.48		5.31		8.62		0.28		0.25	
Per cent contribution														
Females			47.16		45.64		75.56		48.49		19.58		17.61	
Males			28.38		42.27		6.47		18.41		16.63		18.46	
Females *x* males			24.45		12.07		17.95		33.09		63.78		63.92	

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		6.30	*++	1532.96	**++	72.66		87.55	**++	2168.20	+	9.35	
males	9		2.82		208.26	+	38.03		18.29		2450.64	*++	5.92	
Females *x* males	27		1.84	**	98.16	**	43.13	**	13.45	**	853.19	**	5.00	*
Error	78		0.29		45.18		10.22		4.68		328.91		2.67	
Variance components														
	n_1	n_2												
σ^2_f	3	27	0.20		49.59	**	2.08		2.76		61.30	**	0.22	
σ^2_m	9	27	0.21		13.59	**	2.31	*	1.13		176.81	**	0.27	
σ^2_{fm}	27	78	0.51		17.66	**	10.97	**	2.92	**	174.76	**	0.77	
σ^2_{GCA}		27	0.20 (6)		39.30 (4)	**	2.14 (6)		2.29 (4)		94.31 (10)	**	0.23 (7)	
σ^2_{SCA}	27	78	0.51		17.66	**	10.97	**	2.92	**	174.76	**	0.77	
$\sigma^2_{GCA}/\sigma^2_{SCA}$			0.39		2.22		0.19		0.78		0.54		0.30	
Per cent contribution														
Females			20.07		50.40		12.63		33.22		12.60		12.96	
Males			26.97		20.54		19.84		20.82		42.74		24.64	
Females *x* males			52.95		29.05		67.51		45.95		44.64		62.38	

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

+, ++ Significant at 5 per cent and 1 per cent levels of significance when females and males tested for significance when females x males interaction found significant for respective trait, respectively

Table 2: Estimates of general combining ability (gca) effects for different characters in castor

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												
JP 96	-0.66		-0.61		9.45	**	-0.69		5.29	**	4.06	**
JP 104	-2.51	**	-3.84	**	-4.13	**	-3.43	**	-3.39	**	-2.13	**
SKP 84	3.35	**	4.89	**	-2.06	*	3.25	**	-2.89	**	-1.41	*
SKP 106	-0.17		-0.43		-3.26	**	1.17	*	-2.01	*	-0.91	
SE(g_i)	0.39		0.90		0.79		0.46		0.83		0.57	
Males												
JI 431	0.39		-4.04	**	-1.81		-1.28	*	1.24		1.68	
JI 432	0.49		-1.86		3.42	**	-2.33	**	1.95	*	1.72	
JI 433	2.04	**	1.93		1.36		-0.60		3.84	**	4.54	**
JI 434	1.95	**	2.60		1.39		1.08		-0.14		-1.67	
JI 435	1.52	*	-0.38		2.75	*	1.06		-2.85	**	-3.19	**
JI 437	1.72	*	-4.24	**	-2.81	*	-3.11	**	-2.03	*	-2.31	*
JI 438	1.23		-0.03		-3.41	**	4.26	**	-3.90	**	-5.16	**
JI 439	1.40	*	-2.46		-4.33	**	-0.96		-4.78	**	-6.58	**
JI 440	1.45	*	4.46	**	2.74	*	3.95	**	-3.51	**	-4.28	**
JI 441	2.79	**	4.03	**	0.20		4.63	**	1.42		1.96	*
SE(g_j)	0.65		1.45		1.10		0.67		0.97		0.95	

Table 2: Contd…

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												
JP 96	0.90	**	6.70	**	3.18	**	1.84	*	43.66	**	2.73	**
JP 104	0.76	*	-9.40	**	-2.78	**	2.68	**	-12.21	*	-2.03	**
SKP 84	0.28		-1.45		-2.47	**	1.31		1.75		-2.59	**
SKP 106	-0.95	**	8.24	**	-1.52	*	-3.54	**	52.26	**	1.04	*
SE(g_i)	0.30		1.93		0.58		0.69		5.38		0.52	
Males												
JI 431	0.39		5.42		-2.16		3.32	**	13.22		3.59	**
JI 432	0.10		-4.83		3.78	**	2.01	*	12.34		-2.15	**
JI 433	1.13	*	8.84	**	4.98	**	-1.70		5.86		3.20	**
JI 434	-0.98	*	-7.22	*	-4.14	**	-2.25	*	-21.17	**	1.55	*
JI 435	0.50		3.59		-2.04		-3.90	**	28.39	**	2.75	**
JI 437	-0.81		11.96	**	5.01	**	-2.55	*	9.08		1.18	
JI 438	1.15	*	-5.67	*	-2.20		4.43	**	5.17		-2.60	**
JI 439	-1.78	**	3.05		-3.84	**	1.92		-11.65		-3.12	**
JI 440	-1.21	**	-7.39	*	3.35	**	-2.76	*	-33.22	**	1.28	
JI 441	0.81		-6.45	*	3.01	*	4.59	**	30.30	**	1.38	
SE(g_j)	0.43		2.84		1.15		1.02		7.14		0.76	

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

Table 3A: Estimates of specific combining ability (sca) effects 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

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)	
JP 96 × JI 431	-1.32		-1.30		-4.05		-1.07		7.52	**	6.88	*
JP 96 × JI 432	2.09	*	4.55	*	6.76	**	1.97	**	14.18	**	11.41	**
JP 96 × JI 433	0.47		-1.80		-6.56	**	-2.16	**	2.06		-0.25	
JP 96 × JI 434	3.15	**	-0.49		-7.13	**	1.42	*	-11.75	**	-9.24	**
JP 96 × JI 435	-0.36		-2.17		7.38	**	1.17		14.24	**	12.30	**
JP 96 × JI 437	0.63		-1.82		3.31		1.82	**	-4.93	*	-3.65	
JP 96 × JI 438	-0.83		1.20		-4.11		-1.76	**	-11.33	**	-8.66	**
JP 96 × JI 439	0.06		1.65		-3.13		-0.62		-10.75	**	-7.91	**
JP 96 × JI 440	-3.61	**	0.21		6.33	**	0.62		6.74	**	6.38	*
JP 96 × JI 441	-0.28		0.98		-2.80		-1.39	*	-5.99	*	-4.30	
JP 104 × JI 431	-0.35		-5.43	*	1.76		-0.23		2.31		1.46	
JP 104 × JI 432	-1.66	*	-2.40		-1.41		-1.25	*	-2.82		1.26	
JP 104 × JI 433	-2.56	**	1.48		5.62	*	2.01	**	3.15		3.59	
JP 104 × JI 434	-1.18		-3.04		5.34	*	1.33	*	3.60		2.46	
JP 104 × JI 435	1.99	*	-1.16		2.09		1.81	**	-10.01	**	-10.25	**
JP 104 × JI 437	-0.09		3.45		3.56		-1.53	*	6.46	**	4.06	
JP 104 × JI 438	-1.31		5.44	**	2.60		-2.52	**	2.90		-0.82	
JP 104 × JI 439	0.37		1.56		-5.14	*	-1.65	*	2.67		-0.66	
JP 104 × JI 440	1.72	*	1.01		-5.08	*	0.13		-2.40		-3.30	
JP 104 × JI 441	3.08	**	0.07		-5.34	*	-1.08		2.12		2.18	

Table 3A: Contd…

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)	
SKP 84 × JI 431	1.17		5.68	**	4.56	*	0.18		3.45		2.79	
SKP 84 × JI 432	0.23		0.61		-3.03		-1.70	**	-7.27	**	-7.66	**
SKP 84 × JI 433	2.67	**	0.08		-2.35		-1.96	**	-9.05	**	-9.53	**
SKP 84 × JI 434	-2.41	**	0.96		-2.34		-2.11	**	-2.80		-1.79	
SKP 84 × JI 435	-1.18		0.31		-2.24		-0.10		2.97		3.68	
SKP 84 × JI 437	-1.20		-1.71		-3.98		1.41	*	6.69	**	4.93	
SKP 84 × JI 438	2.42	**	-4.26	*	-3.49		2.70	**	8.48	**	7.98	**
SKP 84 × JI 439	0.19		-1.73		0.62		1.16		2.48		-0.06	
SKP 84 × JI 440	-0.21		-0.72		2.77		-1.78	**	-5.75	*	-3.70	
SKP 84 × JI 441	-1.67	*	-1.21		3.49		2.20	**	4.79	*	3.38	
SKP 106 × JI 431	0.49		1.05		-4.27	*	0.13		-9.29	**	-8.14	**
SKP 106 × JI 432	-0.65		-1.75		-4.31	*	-0.02		-8.07	**	-7.01	*
SKP 106 × JI 433	-0.58		0.23		3.29		2.11	**	7.83	**	6.19	*
SKP 106 × JI 434	0.44		4.57	*	4.13		0.36		10.95	**	8.58	**
SKP 106 × JI 435	-0.44		4.02	*	-7.23	**	-2.88	**	-7.20	**	-5.79	*
SKP 106 × JI 437	0.66		0.08		-2.89		-1.70	**	-8.22	**	-5.34	*
SKP 106 × JI 438	-0.26		-4.37	*	5.00	*	-1.42	*	3.94		1.50	
SKP 106 × JI 439	-0.63		-1.48		5.65	*	1.11		9.59	**	8.64	**
SKP 106 × JI 440	2.09	*	-0.50		-4.02		0.03		-2.59		0.62	
SKP 106 × JI 441	-1.12		0.16		4.64	*	-1.72	**	3.06		-1.25	
SE(s_{ij})	0.85		2.04		2.15		0.61		2.30		2.57	

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

Table 3B: Estimates of specific combining ability (sca) effects 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

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 (%)	
JP 96 × JI 431	1.16	*	9.27	**	1.79		-3.92	**	-8.87		0.84	
JP 96 × JI 432	1.27	**	-11.18	**	-0.33		1.43		-15.95	*	-0.77	
JP 96 × JI 433	0.32		5.47		0.37		2.19	*	-11.14		-0.83	
JP 96 × JI 434	0.34		-7.02	*	-5.67	**	-4.05	**	-13.69	*	-0.76	
JP 96 × JI 435	0.10		4.32		0.74		1.90		-6.44		-0.08	
JP 96 × JI 437	-0.32		-2.90		-1.64		3.33	**	31.28	**	-0.00	
JP 96 × JI 438	-0.27		2.26		2.03		1.79		8.68		0.73	
JP 96 × JI 439	-0.92	*	3.08		2.67		-1.97		-8.45		1.90	**
JP 96 × JI 440	-1.00	*	9.70	**	0.43		2.57	*	17.46	*	-0.32	
JP 96 × JI 441	-0.42		-9.03	**	-0.39		-1.29		-10.86		-0.69	
JP 104 × JI 431	-0.11		-6.68	*	-3.98	*	-2.33	*	-10.00		0.39	
JP 104 × JI 432	-0.13		-3.75		1.76		2.28	*	19.81	**	0.31	
JP 104 × JI 433	-0.43		-2.82		2.32		-2.72	*	7.35		-0.01	
JP 104 × JI 434	-0.15		8.62	**	0.17		3.02	**	29.58	**	-1.73	**
JP 104 × JI 435	0.93	*	-2.32		-1.93		1.64		-13.35	*	-0.31	
JP 104 × JI 437	0.38		6.38	*	-0.01		-3.40	**	-11.22		0.85	
JP 104 × JI 438	0.09		-2.88		4.61	*	-1.23		-12.08		-0.30	
JP 104 × JI 439	-0.25		-3.22		0.57		3.07	**	-9.54		-0.81	
JP 104 × JI 440	0.29		-8.80	**	2.48		1.89		-29.83	**	0.48	
JP 104 × JI 441	-0.42		7.48	*	-5.99	**	-2.22	*	20.28	**	1.15	

Table 3B: Contd…

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 (%)	
SKP 84 × JI 431	-1.37	**	-11.49	**	-1.97		2.36	*	14.48	*	-1.82	**
SKP 84 × JI 432	1.00	*	6.73	*	3.94	*	-1.97		-12.92	*	-1.04	
SKP 84 × JI 433	-0.48		6.28	*	3.10		2.28	*	-7.52		-0.09	
SKP 84 × JI 434	0.46		-8.48	**	-0.20		2.16	*	-18.08	**	0.85	
SKP 84 × JI 435	0.41		3.91		-2.35		1.64		24.61	**	-0.04	
SKP 84 × JI 437	0.13		-7.54	*	1.13		2.61	*	25.75	**	1.97	**
SKP 84 × JI 438	-0.88	*	-4.87		-1.85		-5.29	**	-14.43	*	0.15	
SKP 84 × JI 439	0.23		4.90		-0.72		-1.11		7.74		-0.24	
SKP 84 × JI 440	0.65		-8.05	**	-5.01	*	-1.09		6.14		1.81	**
SKP 84 × JI 441	-0.09		8.53	**	3.96	*	-1.38		-14.78	*	-1.24	*
SKP 106 × JI 431	0.52		-3.45		4.17	*	3.89	**	5.38		0.58	
SKP 106 × JI 432	-1.71	**	8.20	**	-5.37	**	-1.74		16.06	*	1.50	*
SKP 106 × JI 433	0.59		-8.93	**	-5.80	**	-1.65		8.31		0.95	
SKP 106 × JI 434	-0.66		6.87	*	5.69	**	-1.03		-9.81		1.64	*
SKP 106 × JI 435	-1.24	**	-5.91	*	3.54		-3.19	**	-10.82		0.44	
SKP 106 × JI 437	-0.19		4.06		0.52		-2.53	*	-43.81	**	-2.52	**
SKP 106 × JI 438	1.05	*	5.48		-4.78	*	4.73	**	17.94	**	-0.58	
SKP 106 × JI 439	0.64		-4.76		-2.52		-1.98		12.25		-0.84	
SKP 106 × JI 440	0.05		7.14	*	2.11		-3.37	**	15.22	*	-1.96	**
SKP 106 × JI 441	0.93	*	-6.99	*	2.42		2.95	**	9.36		0.79	
SE(s_{ij})	0.44		2.88		1.84		1.05		6.47		0.61	

***, ** 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 four parent's *viz*., JP 96 and SKP 106 among female parents, and JI 441 and JI 435 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. Out of ten top most high yielding cross combinations, four cross combinations *viz*., SKP 106 × JI 432, SKP 106 × JI 438, JP 104 × JI 441 and SKP 84 × JI 431 also manifested the high and desirable sca effect for seed yield per plant, which involved good x average, good x average, poor x good and average x average general combiners, respectively, could be exploited for castor genetic improvement.

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