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

ABSTRACT

Combining ability for seed yield and its component traits in castor was studied using line × tester mating design involving three diverse pistillate lines and fourteen inbred lines. Analysis of variance revealed that, The estimates of σ^2gca were higher than the corresponding σ^2sca for plant height upto primary raceme, effective number of spikes per plant, seed yield per plant, 100 seed weight and 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. Two parental lines, SKP 84 and Geeta among the females and ANDCI 14, ANDCI 8, ANDCI 12-2, SKI 343 and DCS 109 among the males, exhibited good general combining ability effects for seed yield per plant and at least for two to three important yield contributing attributes. The best hybrids, SKP 84 × ANDCI 14, SKP 84 × ANDCI 10-3 and Geeta × SKI-343 registered high heterobeltiosis, standard heterosis and desirable highest sca effects for seed yield alongwith high *per se* performance may be directly exposed for commercial cultivation and may be advanced for development of parental genotypes by incorporating all the desirable characters in parental genotypes, which showed their superiority for seed yield and yield attributing characters.

Key words : Combining ability, GCA, SCA and Gene action.

INTRODUCTION

Castor (*Ricinus communis* L.) appertains to family Euphorbiaceae. The castor with 2n = 20 chromosome numbers and it is greatly cross-pollinated up to the level of 50 per cent. It is indigenous to Eastern Africa and most probably originated in Ethiopia. It is semi-tropical, indeterminate perennial plant, but it has naturalized as annual/seasonal crop plant throughout the world in frost free zones. It has an ability to grow under low-rainfall and low-fertility conditions, and hence it is most suitable for dry land farming. Because of hardiness, it plays an important role in the economy of arid and semi-arid regions of the country. Castor productivity in India is more than world average and it ranks first among the major castor producing countries *viz*., India, China, Brazil and Thailand. India's dominance is evident, with 9.2 lakh hectares dedicated to castor, yielding 1791 kg/ha,and fulfilling 88 per cent of the world's castor oil imports, valued at 87.54 billion rupees (Anonymous, 2022b). Besides meeting the domestic demands, India earns sizeable foreign exchange (Rs. 8190 crores) through the export of castor oil and its derivatives (Anon.,

2023) and the whole world is highly dependent on India for the supply of this oil, which is used in production of some vital chemicals. Castor oil has great industrial value as it is used for the makeup of soaps, refined and perfumed hair oil, printing inks, varnishes, synthetic resins, carbon paper, lubricant, ointments, cosmetics and processed leather.

The success of any breeding programme largely depends upon proper selection of parents in any planned hybridization programme. An information on nature and magnitude of gene effects of matricate character/s is useful for adopting breeding methodology in any crop; while, the information on nicking ability of parents and their hybrids is useful in sorting out parents for their uses in future crop improvement work, and the hybrids worth to be advanced. Genetic components analysis alongwith combining ability analysis refers powerful tool to discriminate good as well as poor combiners and to choose appropriate parental material in breeding programme. It requires extensive and detailed genetic assessment of existing germplasm as well as newly developed promising genotype, which could be used in future breeding programme or could be directly released as a cultivar after thorough testing. For improving the yield potential of varieties and hybrids, the decision should be made on the choice of the right parents for hybridization. Though *per se* performance is taken as selection criteria, proper information on the combining ability and gene action for seed yield per plant and its component characters involved in the inheritance in different parents and their crosses would be more helpful 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.

MATERIALS AND METHODS

Experimental material consisting of 61 entries comprised of three pistillate lines (VP 1, SKP 84 and Geeta, used as lines/females) and ten inbred lines (ANDCI 1, ANDCI 8, ANDCI 14, ANDCI 10-3, ANDCI 10-5, ANDCI 12-2, DCA 97, SKI 215, GP 640, SKI 315, SKI 343, 48-1, RB 1 and DCS 97, used as testers/males) and their 42 hybrids developed through line × tester mating design along with two standard check hybrids (GCH 7 and GNCH 1) were evaluated in a randomized block design with three replications. The materials were evaluated during *kharif-rabi* 2017-18 at the Regional Research Station, Anand Agricultural University, Anand. 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*., days to 50 per cent flowering, number of nodes up to primary raceme, days to maturity of primary raceme, plant height up to primary raceme (cm), total length of primary raceme (cm), effective length of primary raceme (cm), number of capsules on primary raceme, effective number of spikes per plant, seed yield per plant (g), shelling out-turn (%), 100 seed weight (g) and oil content (%). Days to 50 per cent flowering, 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 DISCUSSIONS

The variation present in the hybrids was partitioned into sources attributable to lines, testers, lines × testers and error sources. Analysis of variance for combining ability revealed that mean squares due to lines were highly significant for all the characters except total and effective length of primary raceme and shelling out-turn (Table 1). Whereas, mean square due to testers were significant for total and effective length of primary raceme and oil content. The mean squares due to line × tester interaction were highly significant for all the characters except oil content suggesting that line × tester interaction variance contributed largely for total genetic variance, and both lines and testers interacted differently in cross combinations. 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 Lavanya and Chandramohan (2003), Maheshvari (2007), Sridhar *et al.* (2008), Aher *et al.* (2015), Golakiya *et al.* (2015), Makani *et al.* (2015), Sapovadia *et al.* (2015), Patel (2016), Jalu *et al.* (2017), Kugashiya *et al.* (2017), Patel *et al* (2017), Punewar *et al* (2017), Bindu Priya *et al.* (2018), Delvadiya *et al.* (2018), Dushyant *et al.* (2018), Chaudhari *et al* (2020), Gerbaba, Rebuma. *et al.* (2024),

The genetic variance σ^2gca and σ^2sca was significant for all the characters studied except σ^2gca for total and effective length of primary raceme and shelling out-turn and σ^2sca for oil content indicating importance of both additive and non-additive genetic variance for inheritance of these characters. However, variance ratio (σ^2_{gca} / σ^2_{sca}) was more than one, suggesting the preponderance of additive genetic variance for seed yield per plant, plant height upto primary raceme, effective number of spikes per plant, 100 seed weight and oil content. The ratio was less than one for rest of the characters except number of capsules in primary raceme and shelling out-turn indicating preponderance of non-additive genetic variance. For shelling out-turn the ratio is one and for number of capsules on primary raceme ratio is near to one indicating importance of both variance. The predominance of additive gene action for seed yield and its component traits were also reported by Makani *et al.* (2015), Patel (2016), Jalu *et al.* (2017), Kugashiya *et al.* (2017), Patel *et al* (2017), Panera *et al* (2018), Sharma *et al* (2024).

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 additive gene action and high heterosis observed for seed yield and yield attributing characters, it is suggested that good transgressive segregants could profitably be found in castor on commercial scale.

The above one value of average degree of dominance for the characters days to 50 per cent flowering, number of nodes upto primary raceme, days to maturity of primary raceme, total and effective length of primary raceme had, which revealed overdominance behavior of interacting alleles. The estimates of degree of dominance were below unity for plant height upto primary raceme, effective number of spikes per plant, seed yield per plant, 100 seed weight and oil content suggesting existence of additivity of gene with partial dominance. The values close to one of degree of dominance for number of capsules on primary raceme and shelling out-turn indicates presence of complete dominance.

The general combining ability effects of lines and/or testers were estimated only for those characters which had significant values for mean sum of square for respective sources. Accordingly, specific combining ability effects of crosses were estimated for the characters which registered significant values of mean sum of square for line × tester interactions. Accordingly, among parents, Geeta and SKP 84 from lines were good/average combiner for seed yield per plant and most of the yield contributing characters. Testers ANDCI 8, ANDCI 14, ANDCI 12-2, SKI 343 and DCS 109 were good combiner for total and effective length of primary raceme. These parents may be used for development of promising hybrids. Among pistillate lines, Geeta was found good general combiner for seed yield per plant, number of capsules on primary raceme, effective number of spikes per plant, 100 seed weight and oil content and average combiner for shelling out-turn and effective length of primary raceme; SKP 84 was also found good general combiner for effective number of spikes per plant and shelling out-turn; and VP 1 was found good general combiner for days to 50 % flowering, number of nodes upto primary raceme, days to maturity of primary raceme and plant height upto primary raceme (Table 2).

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 or pseudo additive gene effect *i.e.* additive epistatic are important, the choice of parents on the basis of *per se* performance may be more effective. Similar findings have also been reported by Lavanya and Chandramohan (2003), Maheshvari (2007), Golakiya *et al.* (2015), Makani *et al.* (2015), Patel (2016), Jalu *et al.* (2017), Kugashiya *et al.* (2017) and Bindu Priya *et al.* (2018). 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.

Likewise, among the male parents, the mean square values for testers were non-significant for all the characters except total and effective length of primary and oil content hence all the testers for said characters were considered as average general combiners. Among the good general combiner, ANDCI 8 for total length of primary raceme effective length of primary raceme and oil content and ANDCI 14, ANDCI 12-2, SKI 343 and DCS 109 were good general combiner for total length of primary raceme and effective length of primary raceme but average poor combiner for oil content.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 3) that none of the crosses was consistently superior for all the traits. Out of 42 hybrids studied, 11 cross combinations exhibited significant and positive sca effects for seed yield per plant. Among those hybrids SKP 84 × ANDCI 14 (G × A), SKP 84 × ANDCI 10-3 (G × A), Geeta × SKI 315 (G × A), Geeta × SKI-343 (G × A) and VP 1 × DCS 97 (P × A) were the top five ranking for seed yield and were also good specific combiners for seed yield. In respect to gca effects of parents involved in a particular cross, crosses could be grouped in to resultant of six different categories of good, average and poor general combiner parents, *viz*. G × G, G × A, G × P, A × A, A × P and P × P parents. The crosses exhibited high sca effect did not always involve both good general combiner parents with high gca effects, there by suggesting importance of intra as well as inter- allelic interactions. The high sca effects of crosses in general corresponds to their high heterotic response, but these might also be accompanied by poor and/or average gca effects of the parents (Table 4). For seed yield per plant, total 11 hybrids, SKP 84 × ANDCI 14 (79.86*), SKP 84 × ANDCI 10-3 (76.94**), Geeta × SKI 315 (75.85**), Geeta × SKI 343 (59.52**) VP 1 × DCS 97 (49.64**), VP 1 × ANDCI 8 (38.32**), VP 1 × DCS 109 (34.3*), Geeta × ANDCI 12-2 (32.19**), SKP 84 × ANDCI 10-5 (28.04**), VP 1 × GP 640 (23.43*), Geeta × SKI 215 (22.33*) exerted significant and positive sca effects.

The top three crosses on the basis of their *per se* performance, heterobeltiosis, standard heterosis and sca effects (Table 5) for different characters displayed difference in their ranking, which suggested that crosses exhibiting high sca effects would not necessarily give either highest mean value or high heterotic effect and *vice versa*, therefore, while selecting a cross for further uses one has to consider all aspects independently.The crosses having high sca effects for seed yield per plant also registered desirable sca effects for most of the yield component characters, justifying phenomenon of seed yield is being dependent complex character and it is outcome of direct and indirect effect of different component characters. The hybrids which exhibited high sca effect did not always involve both the parents as good general combiner with high gca effect, thereby suggesting importance of intra as well as inter-allelic interactions. The high sca effect of hybrids in general corresponds to their high heterotic effects, but these might also be accompanied by poor and/or average gca effects of the parents.

The crosses having high sca effects for seed yield per plant also registered desirable sca effects for most of the yield component characters, but those might not necessarily have higher sca effects for the component characters, which suggested cumulative effects of various yield contributing attributes as a high sca effect for seed yield, and thereby high heterotic effects as well. This also appropriately suggest that yield is a complex character dependent on number of component characters, and suitable recombination of genes governing these characters might have produced promising hybrids, therefore, none of the hybrids had desirable sca effects for all the characters. However, hybrids SKP 84 × ANDCI 14, SKP 84 × ANDCI 10-3, Geeta × ANDCI 12-2, Geeta × SKI 343 registered positive highest sca effects for seed yield alongwith high *per se* performer, high heterobeltiosis and standard heterosis. Therefore, these hybrids may also be exposed and heterosis breeding programme may be strengthened with aim of improvement of pistillate lines and inbreds by incorporating all the desirable characters in parental genotypes, which showed their superiority for seed yield and yield attributing characters.

CONCLUSIONS

According to the studies on general combining ability in castor, it can be concluded that among parent's *viz.*, Geeta and SKP 84 from lines and ANDCI 8, ANDCI 14, ANDCI 12-2, SKI 343 and DCS 109 were good /average general combiners for seed yield and line ANDCI 8 was good general combiner for total and effective length of primary raceme and oil content. Therefore, these parents may be involved in building up desirable gene pool in castor. The hybrids SKP 84 × ANDCI 14, SKP 84×ANDCI 10-3 and Geeta×SKI-343 registered positive highest sca effects for seed yield along with high *per se* performer, high heterobeltiosis and standard heterosis. Therefore, these hybrids may also be exposed and heterosis breeding programme may be strengthened with aim of improvement of pistillate lines and inbreds by incorporating all the desirable characters in parental genotypes, which showed their superiority for seed yield and yield attributing characters.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

REFERENCES

Anonymous (2022b). Government of India. Agricultural Statistics at a Glance. Ministry of Agriculture & Farmers Welfare, Department of Agriculture & Farmers Welfare, Economics & Statistics Division.

Anonymous (2023) Export of castor oil 2021 to 2023 (JAN-DEC) AND JAN-NOV 2024 https://seaofindia.com.

Aher, A. R., Patel, K. V., Patel, M. P., & Patel, J. A. (2015). Genetic analysis of seed yield and component characters over environments in castor (*Ricinus communis* L.). *Elect. J. Pl. Breed.*, 6 (1), 141-149.

Bindu Priya, P., Nagesh Kumar, M. V., Gouri Shankar, V., Seshu, G., Anuradha, G., & Venkata Ramana, M. (2018). Studies on magnitude of genetic variability and estimates of combining ability for yield and its contributing traits among improved lines of castor (*Ricinus communis* L.). *Int. J. Microbiol. App. Sci.*, 7(1), 3031-3041.

Chaudhari G 2020. Heterosis and combining ability analysis for oil yield and its components in castor (*Ricinus communis L.*). *Bioscience Trends*, 7(22): 3757-3760.

Comstock, R. E., & Robinson, H. E. (1952). Genetic parameters, their estimation and significance. *Proceeding 6th International Grassland Congress*, 1, 284-291.

Delvadiya IR, Dobariya KL, Ginoya AV and Patel JR. 2018. Combining ability analysis for seed yield per plant and its components in castor (*Ricinus communis L.). Journal of Pharmacognosy and Phytochemistry*, E-ISSN: 2278-4136, P-ISSN: 2349-8234 JPP 2018; 7(4): 1146-1153

Dushyant Dube, Ronak Bhakta, Kanak Bhati and Vaibhav Lodhum, (2018). Studies on combining ability and heterosis for seed yield and yield components in Rabi castor (*Ricinus communis L.*); *The Pharma Innovation Journal*; 7(5): 171-175. ISSN (E): 2277- 7695 ISSN (P): 2349-8242.

Gerbaba, Rebuma. (2024). Estimate of Combining Ability and Heterosis for Seed Yield and Yield Component Traits in Castor (*Ricinus Communis L.). International Journal of Scientific and Research Publications.* 14. 24-37.

Golakia, P. R., Monapara, B. A., & Poshiya V. K. (2015). Identification of superior donor parents for earliness through combining ability in castor. *Int. J. Res. Plant Sci.*, 5(3), 26-31

Jalu, R. K., Patel, J. B., Patel, C. K., & Paneliya, M. R. (2017). 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.

Kempthorne, O. (1957). *An introduction to genetics statistics*. John Wiley and Sons, Inc., New York. pp. 468-470.

Kugashiya, K. G., Patel, B. N., & Vekariya, K. J. (2017). Study of heterosis for seed yield and its component traits in castor [*Ricinus communis* L.). *Int. J. Curr. Microbio. App. Sci*., 6(8), 66-74.

K.P. Patel, M.P. Patel, N.R. Joshi and J.A. Patel (2017).General and specific combining ability for quantitative characters in castor (*Ricinus communis* L.). *Electronic Journal of Plant Breeding*, 8(2): 422-427

Lavanya, C., & Chandramohan, Y (2003). Combining ability and heterosis for seed yield and yield components in castor (*Ricinus communis* L.). *J. Oilseeds Res*., 20 (2), 220-224.

Maheshvari, B. H. (2007). Genetic architecture of yield and its components characters in castor (*Ricinus communis* L.) by diallel analysis. (Master's thesis, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Dantiwada).

Makani, A. Y., Patel, M. P., Patel, P. S., Patel, P. C., & Pandya, M. M. (2015). Genetic architecture for seed yield, its components and wilt resistance over environments in castor (*Ricinus communis* L.). *International J. Agric. Sci. and Res.*, 5 (6), 313-320.

Panera, A., Pathak, A. R., Madariya, R. B., & Barad, S. H. (2018). Gene action for seed yield and its component traits in castor (*Ricinus communis L.*) using graphical and numerical approach of diallel analysis. *Journal of Pharmacognosy and Phytochemistry,* 7(4), 1870-1876.

Patel, J. J. (2016). *Genetic analysis of seed yield and its component characters in castor* (*Ricinus communis* L.). (Master's thesis, Anand Agricultural University, Anand Gujarat).

Punewar A, Patil AS, Nandanwar HR, Patel SM, Patel B N. (2017) Genetic dissection of heterosis and combining ability in castor (*Ricinus communis L.*) with line × tester analysis. *Journal of Experimental Biology and Agricultural Sciences*. 5(1):77-86.

Sapovadia, M. H. (2015). Heterosis, gene action and combining ability over environments for seed yield and its components in castor. (Doctoral thesis, Junagadh Agricultural University, Junagadh).

Sharma, V., Kumhar, S.R., Mehriya, M., Meena, R.C and Ramesh. (2024) Gene action and combining ability analysis for seed yield and component traits in castor genotypes. *Annals of Arid Zone* 63(4): 71-77

Sridhar, V., Dangi, K. S., Reddy, A. V., Sudhakar, R., & Sankar, A. S. (2008). Combining ability studies for yield and its components in castor (*Ricinus communis* L.). *J. Oilseeds Res.*, 25 (2). 193-196.

Table 1: Analysis of variance for combining ability

Source of Variation	df	Days to 50 per cent flowering	No. of nodes upto primary raceme	Days to maturity of primary raceme	Plant height upto primary raceme	Total length of primary raceme	Effective length of primary raceme	No. of capsules on primary raceme	Effective no. of spikes per plant	Seed yield per plant	Shelling out-turn	100 seed weight	Oil content
Replications	2	10.58	6.78**	43.49	12.8	3.72	11.85	39.65	0.55	917.27	157.97*	0.34	10.37**
Lines	2	576.5**	85.25**	1891.16**	4727.34**	163.54	163.14	8302.26**	578.94**	173707.55**	660.39**	601.02**	45.22**
Testers	13	35.64	10.54	304.63	204.54	150.29*	161.93*	252.65	7.72	3709.42	138.63	9.9	6.19**
Line × Tester	26	51.07**	6.83**	243.69**	110.88**	66.69**	70.33**	454.56**	12**	5764.52**	72.41**	24.61**	1.37
Error	82	7.6	0.69	16.28	13.68	7.92	6.4	35.85	0.72	755.94	34.02	0.92	1.2
Estimates of components of genetic variance and related parameters													
σ^2 gca (line)		12.51**	1.87**	39.23**	109.92**	2.31	2.21	186.85**	13.50**	3998.64**	14.00**	13.72**	1.04**
σ^2 gca (tester)		-1.71	0.41	6.77	10.41	9.29**	10.18**	-22.43	-0.48	-228.34	7.36	-1.63	0.54**
σ^2gca (average)		10.00**	1.61**	33.50**	92.36**	3.54	3.62	149.92**	11.03**	3252.7**	12.83**	11.01**	0.95**
σ^2sca		14.49**	2.05**	75.80**	32.40**	19.59**	21.31**	139.57**	3.76**	1669.53**	12.80**	7.89**	0.06
σ^2gca/ σ^2sca		0.69	0.79	0.44	2.85	0.18	0.17	1.07	2.94	1.95	1.00	1.40	16.81
σ^2 A		40.00	6.44	133.99	369.42	14.15	14.46	599.67	44.13	13010.82	51.31	44.06	3.82
σ^2 D		57.96	8.19	303.21	129.60	78.35	85.24	558.29	15.04	6678..12	51.18	31.58	0.23
$[\sigma^2 D / \sigma^2 A]^{0.5}$		1.20	1.13	1.50	0.59	2.43	2.43	0.96	0.58	0.72	1.00	0.85	0.25

*, ** Significant at 5% and 1% level of significance, respectively.

Table 2 : Top Lines and Testers parents with respect to gca effects along with *per se* performance for various traits in castor

Sr. No.	Characters	Lines		Testers	
		***Per se* performance**	**gca effects**	***Per se* performance**	**gca effects**
1	**Seed yield per plant**	Geeta	Geeta	SKI 215	-
		SKP 84	-	48-1	-
		VP 1	-	SKI 315	-
2	**Days to 50 per cent flowering**	VP 1	VP 1	ANDCI 10-5	-
		SKP 84	-	DCS 109	-
		Geeta	-	ANDCI 8	-
3	**Number of nodes upto primary raceme**	VP 1	VP 1	GP 640	-
		Geeta	-	SKI 343	-
		SKP 84	-	ANDCI 10-5	-
4	**Days to maturity of primary raceme**	VP 1	VP 1	ANDCI 10-5	-
		SKP 84	SKP 84	DCS 109	-
		Geeta	-	ANDCI 8	-
5	**Plant height upto primary raceme**	VP 1	VP 1	DCS 109	-
		SKP 84	-	GP 640	-
		Geeta	-	SKI 315	-
6	**Total length of primary raceme**	SKP 84	-	ANDCI 12-2	ANDCI 14
		Geeta	-	SKI 343	ANDCI 8
		VP 1	-	DCS 97	SKI 343
7	**Effective length of primary raceme**	SKP 84	-	ANDCI 12-2	ANDCI 14
		Geeta	-	SKI 343	ANDCI 8
		VP 1	-	ANDCI 8	ANDCI 12-2
8	**Number of capsules on primary raceme**	Geeta	Geeta	SKI 215	-
		SKP 84	-	GP 640	-
		VP 1	-	DCS 97	-
9	**Effective number of spikes per plant**	Geeta	Geeta	ANDCI 10-3	-
		SKP 84	SKP 84	SKI 215	-
		VP 1	-	ANDCI 8	-
10	**Shelling out-turn**	SKP 84	SKP 84	RB 1	-
		Geeta	-	SKI 315	-
		VP 1	-	GP 640	-
11	**100 seed weight**	SKP 84	Geeta	SKI 343	-
		Geeta	-	SKI 215	-
		VP 1	-	GP 640	-
12	**Oil content**	SKP 84	Geeta	RB 1	RB 1
		Geeta	-	GP 640	GP 640
		VP 1	-	48-1	48-1

(- = indicate gca effect found non significant)

Table 3 : Three best crosses based on sca effects along with *per se* performance and their gca effects

Sr. No.	Characters	Crosses	sca effects		*Per se* performance (g)
1	Seed yield per plant	SKP 84 × ANDCI 14	79.86**	(G × A)	314.43
		SKP 84 × ANDCI 10-3	76.94**	(G × A)	267.20
		Geeta × SKI 315	75.85**	(G × A)	374.02
2	Days to 50 per cent flowering	SKP 84 × ANDCI 10-5	-6.75**	(P × A)	49.33
		Geeta × ANDCI 14	-6.23**	(P × A)	54.00
		VP 1 × ANDCI 8	-6.02**	(G × A)	44.67
3	Number of nodes upto primary raceme	Geeta × ANDCI 14	-2.55**	(P × A)	18.60
		SKP 84 × ANDCI 14	-1.76**	(P × A)	19.41
		VP 1 × ANDCI 12-2	-1.66**	(G × A)	14.62
4	Days to maturity of primary raceme	Geeta × ANDCI 14	-15.39**	(P × A)	102.33
		VP 1 × ANDCI 8	-13.22**	(G × A)	83.33
		Geeta × SKI 315	-12.94**	(P × A)	100.67
5	Plant height upto primary raceme	SKP 84 × RB 1	-9.30**	(A × A)	41.73
		VP 1 × ANDCI 12-2	-8.39**	(G × A)	40.22
		SKP 84 × SKI 343	-7.50**	(A × A)	49.22
6	Total length of primary raceme	SKP 84 × ANDCI 12-2	6.47**	(A × G)	61.80
		VP 1 × 48-1	6.39**	(A × P)	53.53
		Geeta × SKI 343	5.51**	(A × G)	58.07
7	Effective length of primary raceme	Geeta × SKI 343	7.25**	(A × G)	55.15
		SKP 84 × GP 640	6.16**	(A × P)	53.84
		SKP 84 × ANDCI 12-2	5.62**	(A × G)	57.33
8	Number of capsules on primary raceme	VP 1 × DCS 109	22.02**	(P × A)	95.78
		SKP 84 × ANDCI 8	16.70**	(P × A)	101.83
		SKP 84 × ANDCI 14	15.23**	(P × A)	90.56
9	Effective number of spikes per plant	SKP 84 × ANDCI 14	4.51**	(G × A)	15.21
		Geeta × SKI 343	2.69**	(G × A)	16.83
		Geeta × SKI 315	2.67**	(G × A)	15.20
10	Shelling out-turn	SKP 84 × 48-1	12.28**	(G × A)	71.28
		Geeta × DCS 109	4.83**	(A × A)	66.91
		Geeta × ANDCI 10-5	4.78**	(A × A)	70.90
11	100 seed weight	SKP 84 × ANDCI 14	5.16**	(P × A)	31.12
		VP 1 × DCS 109	4.25**	(P × A)	28.42
		SKP 84 × ANDCI 8	3.71**	(P × A)	31.68
12	Oil content	-	-	-	-
		-	-	-	-
		-	-	-	-

G= good, A= average and P= poor. *,** Denotes significant at P = 5% and P = 1% levels of significance, respectively. Parenthesis indicate the combining ability of parents involved in respective hybrids.
Note: "-" indicated mean square values found non significant

Table 4.: Estimates of specific combining ability (sca) effects of hybrids for seed yield per plant, shelling out-turn, 100 seed weight and oil content

Sr. No.	Hybrids	Seed yield per plant	100 seed weight	Oil content
1	**VP 1 × ANDCI 1**	2.55	-0.65	0.4
2	**VP 1 × ANDCI 8**	38.32 **	-0.27	0.24
3	**VP 1 × ANDCI 14**	-43.22 **	-2.94 **	-0.64
4	**VP 1 × ANDCI 10-3**	-19.68	0.63	-0.14
5	**VP 1 × ANDCI 10-5**	-31.15 **	-1.61 **	0.14
6	**VP 1 × ANDCI 12-2**	-9.18	1.74 **	-0.83 *
7	**VP 1 × 48-1**	-2.36	-0.22	-0.18
8	**VP 1 × DCS 97**	49.64 **	1.25 **	0.17
9	**VP 1 × SKI 215**	-2.8	0.42	1 *
10	**VP 1 × GP 640**	23.43 *	1.96 **	-0.61
11	**VP 1 × SKI 315**	-12.01	-1.02 **	0.79
12	**VP 1 × SKI 343**	-38.33 **	-1.45 **	0.15
13	**VP 1 × RB 1**	10.49	-2.08 **	-0.32
14	**VP 1 × DCS 109**	34.3 **	4.25 **	-0.17
15	**SKP 84 × ANDCI 1**	-2.22	2.91 **	0.26
16	**SKP 84 × ANDCI 8**	-0.95	3.71 **	-0.92 *
17	**SKP 84 × ANDCI 14**	79.86 **	5.16 **	-0.28
18	**SKP 84 × ANDCI 10-3**	76.94 **	2.54 **	0.26
19	**SKP 84 × ANDCI 10-5**	28.04 **	0.24	-0.58
20	**SKP 84 × ANDCI 12-2**	-23.01 *	-1.14 **	-0.09
21	**SKP 84 × 48-1**	19.91	-0.64	0.15

22	**SKP 84 × DCS 97**	-35.84 **	-3.45 **	-0.06
23	**SKP 84 × SKI 215**	-19.53	-2.04 **	0.16
24	**SKP 84 × GP 640**	2.1	-3.49 **	-0.18
25	**SKP 84 × SKI 315**	-63.85 **	-1.92 **	-0.05
26	**SKP 84 × SKI 343**	-21.19 *	-1.67 **	0.01
27	**SKP 84 × RB 1**	-18.25	1.59 **	0.83 *
28	**SKP 84 × DCS 109**	-22.01 *	-1.77 **	0.51
29	**Geeta × ANDCI 1**	-0.33	-2.26 **	-0.66
30	**Geeta × ANDCI 8**	-37.37 **	-3.43 **	0.68
31	**Geeta × ANDCI 14**	-36.64 **	-2.22 **	0.93 *
32	**Geeta × ANDCI 10-3**	-57.26 **	-3.17 **	-0.12
33	**Geeta × ANDCI 10-5**	3.11	1.37 **	0.45
34	**Geeta × ANDCI 12-2**	32.19 **	-0.59	0.92 *
35	**Geeta × 48-1**	-17.55	0.86 *	0.02
36	**Geeta × DCS 97**	-13.8	2.21 **	-0.11
37	**Geeta × SKI 215**	22.33 *	1.62 **	-1.16 **
38	**Geeta × GP 640**	-25.52 *	1.52 **	0.79
39	**Geeta × SKI 315**	75.85 **	2.95 **	-0.74
40	**Geeta × SKI 343**	59.52 **	3.13 **	-0.15
41	**Geeta × RB 1**	7.76	0.5	-0.51
42	**Geeta × DCS 109**	-12.28	-2.48 **	-0.34
S. E. ±		10.54	0.37	0.42
S.E. (Sij- Skl)		14.91	0.52	0.59
CD @ 5%		20.66	0.73	0.82
No. of significant crosses		23	33	7

Positive	11	16	4
Negative	12	17	3

***,**, significant at 5 % and 1 % level of significance, respectively.**

Table 5 : Top three crosses with respect to their *per se* performance, heterobeltiosis (HB), standard heterosis (SH) and sca effects for various traits in castor

	Days to 50 per cent flowering@	No. of nodes upto primary raceme@	Days to maturity of primary raceme@	Plant height upto primary raceme@	Total length of primary raceme#	Effective length of primary raceme@
***per se* performance**	VP 1 × ANDCI 8	VP 1 × ANDCI 10-5	VP 1 × ANDCI 8	VP 1 × ANDCI 12-2	SKP 84 × ANDCI 12-2	SKP 84 × ANDCI 14
	VP 1 × ANDCI 12-2	VP 1 × SKI 315	SKP 84 × RB 1	SKP 84 × RB 1	SKP 84 × ANDCI 14	SKP 84 × ANDCI 12-2
	SKP 84 × RB 1	VP 1 × SKI 343	VP 1 × DCS 109	VP 1 × ANDCI 10-5	Geeta × ANDCI 14	Geeta × SKI 343
HB	SKP 84 × RB 1	SKP 84 × ANDCI 10-3	Geeta × ANDCI 14	Geeta × ANDCI 1	VP 1 × ANDCI 14	VP 1 × ANDCI 14
	Geeta × ANDCI 14	Geeta × DCS 97	SKP 84 × RB 1	Geeta × ANDCI 10-5	VP 1 × DCS 109	VP 1 × DCS 109
	Geeta × RB 1	Geeta × ANDCI 12-2	Geeta × RB 1	SKP 84 × RB 1	VP 1 × SKI 315	VP 1 × GP 640
SH	VP 1 × ANDCI 8	VP 1 × ANDCI 10-5	VP 1 × ANDCI 8	VP 1 × ANDCI 12-2	SKP 84 × ANDCI 12-2	SKP 84 × ANDCI 14
	VP 1 × ANDCI 12-2	VP 1 × SKI 315	SKP 84 × RB 1	SKP 84 × RB 1	SKP 84 × ANDCI 14	SKP 84 × ANDCI 12-2
	SKP 84 × RB 1	VP 1 × SKI 343	VP 1 × DCS 109	VP 1 × ANDCI 10-5	Geeta × ANDCI 14	Geeta × SKI 343
sca effects	SKP 84 × ANDCI 10-5	Geeta × ANDCI 14	Geeta × ANDCI 14	SKP 84 × RB 1	SKP 84 × ANDCI 12-2	Geeta × SKI 343
	Geeta × ANDCI 14	SKP 84 × ANDCI 14	VP 1 × ANDCI 8	VP 1 × ANDCI 12-2	VP 1 × 48-1	SKP 84 × GP 640
	VP 1 × ANDCI 8	VP 1 × ANDCI 12-2	Geeta × SKI 315	SKP 84 × SKI 343	Geeta × SKI 343	SKP 84 × ANDCI 12-2

	No. of capsules on primary raceme#	Effective no. of spikes per plant#	Seed yield per plant#	Shelling out-turn#	100 seed weight#	Oil content#
***per se* performance**	Geeta × SKI 343	Geeta × SKI 343	Geeta × SKI 315	SKP 84 × SKI 343	Geeta × SKI 343	Geeta × GP 640
	Geeta × SKI 215	Geeta × SKI 215	Geeta × SKI 343	SKP 84 × SKI 315	Geeta × SKI 215	Geeta × RB 1
	Geeta × SKI 315	Geeta × ANDCI 12-2	Geeta × ANDCI 12-2	Geeta × ANDCI 1	Geeta × DCS 97	Geeta × ANDCI 10-5
HB	VP 1 × DCS 109	Geeta × SKI 343	Geeta × SKI 343	SKP 84 × SKI 343	Geeta × SKI 343	Geeta × ANDCI 14
	-	Geeta × SKI 315	Geeta × SKI 315	Geeta × ANDCI 10-5	Geeta × SKI 343	Geeta × ANDCI 10-5
	-	Geeta × ANDCI 12-2	Geeta × ANDCI 12-2	SKP 84 × DCS 97	Geeta × DCS 97	Geeta × ANDCI 8
SH	-	Geeta × SKI 343	Geeta × SKI 315	-	Geeta × SKI 343	Geeta × GP 640
	-	Geeta × SKI 215	Geeta × SKI 343	-	Geeta × SKI 215	Geeta × RB 1
	-	Geeta × ANDCI 12-2	Geeta × ANDCI 12-2	-	Geeta × DCS 97	Geeta × ANDCI 10-5
sca effects	VP 1 × DCS 109	SKP 84 × ANDCI 14	SKP 84 × ANDCI 14	SKP 84 × 48-1	SKP 84 × ANDCI 14	-
	SKP 84 × ANDCI 8	Geeta × SKI 343	SKP 84 × ANDCI 10-3	Geeta × DCS 109	VP 1 × DCS 109	-
	-	Geeta × SKI 315	Geeta × SKI 315	Geeta × ANDCI 10-5	SKP 84 × ANDCI 8	-

Note: "#" indicated standard heterosis was estimated over GCH 7 and "@" indicated standard heterosis was estimated over GNCH 1

Note: "-" indicated mean square values found non significant