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Combining ability studies for seed yield and its component traits in castor (*Ricinus communis* L.)

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Abstract
An experiment was conducted for three consecutive years during *kharif*, 2014-15 to 2016-17 involving 40 entries *viz.* two pistillate lines(DPC-23 and M-571), 12 monoecious lines(DCS-64, DCS-86, DCS-102, DCS-105, DCS-107, DCS-108, DCS-109, DCS-110, DCS-112, DCS-118, DCS-119 and DCS-123), their resultant 24 hybrids produced through line x tester mating design and two check hybrids(DCH-177 and DCH-519). These were tested in randomized block design with three replications at AICRP on Castor, Bhawanipatna, Odisha. The data on ten different characters *viz.* days to 50% flowering of primary raceme, days to maturity of primary spike, plant height up to primary raceme (cm), number of nodes up to primary spike, total length of primary spike (cm), effective length of primary spike (cm), number of effective spikes per plant, number of capsules in primary spike, 100-seed weight (g) and seed yield per plant(g) were recorded in all the three years of experimentation and the pooled mean values were subjected to statistical analysis for combining ability. The general combining ability variance (σ^2GCA) was observed to be higher than the specific combining ability variance (σ^2SCA) for days to 50% flowering of primary raceme, days to maturity of primary spike, plant height up to primary spike, number of nodes up to primary spike and 100-seed weight, which indicated involvement of additive gene action in the inheritance of these five characters. On the other hand, higher magnitude of σ^2SCA as compared to σ^2GCA was observed for total length of primary spike, effective length of primary spike, number of effective spikes per plant, number of capsules in primary spike and seed yield per plant indicating preponderance of non-additive gene action in expression of these five characters. Based on the GCA effects, the parental lines DPC-23, DCS-64, DCS-102 and DCS-105 were good general combiners for earliness; M-571, DCS-108, DCS-109, DCS-110 and DCS-119 were good combiners for total length of primary spike and effective length of primary spike and the genotypes M-571, DCS-110 and DCS-112 were good combiners for characters like number of capsules in primary spike, 100-seed weight and seed yield per plant. These parental lines can be utilized in hybridization programme for improvement of the respective characters. Two cross combinations *viz*., DPC-23 x DCS-123 and M-571 x DCS-105 manifested high and desirable SCA effect for seed yield per plant and for one or more component traits. Besides these two hybrids, other three hybrids *viz*. M-571 x DCS-110, M-571 x DCS-112 and DPC-23 x DCS-110 were better in per se performance and heterosis with respect to seed yield per plant and also exhibited significant SCA effects for one or more component traits. From the results of combining ability, gene action and components of variance, it is concluded that non-additive gene action was predominant for total length of primary spike, effective length of primary spike, number of effective spikes per plant, number of capsules in primary spike and seed yield per plant which indicated that heterosis breeding would be helpful for improving these traits.

Keywords: Castor, Combining ability, GCA, SCA, Gene action

Introduction
Castor (*Ricinus communis* L.) is one commercially important non-edible oilseed crop in the dicotyledonous angiosperm family 'Euphorbiaceae' with 2n = 20. It is indigenous to eastern Africa and Ethiopia is considered to be the most probable site of origin because of presence of high diversity (Moshkin,1986) [11]. India is the world leader in castor production and productivity followed by China and Brazil. In India, Gujarat is the leading state in terms of production and productivity. Andhra Pradesh, Rajasthan, Tamil Nadu, Karnataka, Madhya Pradesh, Uttar Pradesh, Odisha and Maharashtra are the other main castor growing states. Constant efforts are being made to improve seed yield and yield contributing characters of castor through hybridization. Proper selection of parents is very crucial in any planned hybridization programme.

Combining ability analysis is a powerful tool to select good combiners and thus helps in selecting appropriate parental lines for hybridization programme. The concept of general and specific combining ability as a measure of gene action was proposed by Sprague and

Tatum (1942) [18]. The general combining ability (GCA) is the average performance of a genotype in a series of cross combinations and is due to additive and additive x additive gene action which is fixable in nature. Specific combining ability (SCA) is the deviation in performance of a cross combination from that predicted on the basis of general combining abilities of the parents involved in the cross and is due to non-additive gene action which may be due to dominance or epistasis or both and is non-fixable. The presence of non-additive genetic variance is the primary justification for initiating the hybrid breeding programme (Cockerham, 1961) [2]. In the present study, line x tester analysis was attempted which provides a systematic approach for identification of superior parents and crosses and also gives an overall genetic picture of the experimental material. It also helps to identify the genotypes that have general combining ability or specific combining ability in desired direction for their use in future breeding programme.

Materials and Methods

The present investigation involved 14 parental lines *viz*. two pistillate lines (DPC-23 and M-571) and 12 monoecious lines (DCS-64, DCS-86, DCS-102, DCS-105, DCS-107, DCS-108, DCS-109, DCS-110, DCS-112, DCS-118, DCS-119 and DCS-123) which were selected on the basis of their desirable agronomic and morphological differences. The two pistillate lines and twelve monoecious lines (testers) were crossed according to line × tester mating design developed by Kempthorne (1957) [8] to produce 24 F_1 hybrids. The 40 entries involving two pistillate lines, 12 monoecious lines, their resultant 24 hybrids and two check hybrids (DCH-177 and DCH-519) were tested in randomized block design with three replications at AICRP on Castor, Regional Research and Technology Transfer Station, Bhawanipatna, Odisha over three years during *kharif* seasons of 2014-15 (D/S - 29.07.2014), 2015-16 (D/S - 11.08.2015) and 2016-17 (D/S - 17.08.2016). The soil type of the experimental site was vertisol with clay loam texture having pH range of 6.8 to 7.2. The climate of the zone was hot and sub-humid with mean annual rainfall of 1330.5 mm. Each entry was grown in two rows of 6.0m length at a spacing of 90cm x 60 cm. FYM @ 5t/ha was applied during final land preparation. A basal fertilizer dose of 20:40:20 kg N-P_2O_5-K_2O/ha was applied at the time of sowing. Topdressing of 20kg N/ha and earthing up was done after 1st hoeing and weeding operation. Need based plant protection measures were taken as and when required.

Five competitive plants were selected randomly from each entry in each replication for the purpose of recording observations on different characters *viz*., plant height up to primary raceme (cm), number of nodes up to primary spike, total length of primary spike (cm), effective length of primary spike (cm), number of effective spikes per plant, number of capsules in primary spike, 100-seed weight (g) and seed yield per plant (g). Days to 50% flowering of primary raceme and days to maturity of primary spike were recorded on plot basis. The mean values on these ten characters were recorded in all the three years of experimentation and the pooled mean values were subjected to statistical analysis. Cobmining ability analysis was performed using line x tester method as per Kempthorne (1957) [8].

Results and Discussions

The analysis of variance for combining ability over environments (Table 1) revealed significant differences among lines(females) for four characters *viz*. days to 50% flowering of primary raceme, days to maturity of primary spike, plant height up to primary spike and number of nodes up to primary spike. Among testers (males), significant differences were observed for days to 50% flowering of primary raceme, days to maturity of primary spike, plant height up to primary spike, number of nodes up to primary spike and 100-seed weight. Significant mean sum of squares due to females were reported by Dube *et al*. (2018) [4] for days to 50% flowering and number of nodes up to primary spike. For females x males, significant mean squares were recorded for all the ten characters studied. The interaction mean squares due to females x environments were significant for days to maturity of primary spike, plant height up to primary spike, number of nodes up to primary spike and 100-seed weight whereas, interaction mean squares due to males x environments were significant for days to 50% flowering of primary raceme, plant height up to primary spike, number of nodes up to primary spike and 100-seed weight. The interaction mean squares due to females x males x environments were significant for all the characters except plant height and seed yield per plant. The general combining ability variance (σ^2GCA) was higher than the specific combining ability variance (σ^2SCA) for days to 50% flowering of primary raceme, days to maturity of primary spike, plant height up to primary spike, number of nodes up to primary spike and 100-seed weight, which indicated involvement of additive gene action in the inheritance of these five characters. Similar results for plant height up to primary spike and number of nodes up to primary spike was reported by Ramesh *et al*. (2013) [16] and for 100-seed weight by Tank *et al.* (2003) [19]. On the other hand, higher magnitude of σ^2SCA as compared to σ^2GCA was observed for total length of primary spike, effective length of primary spike, number of effective spikes per plant, number of capsules in primary spike and seed yield per plant indicating preponderance of non-additive gene action in expression of these five characters. Non-additive gene action for these traits were also reported by Patel *et al*. (2015) [13] and Punewar *et al*. (2017) [15]. Predominance of non-additive gene action for seed yield was also reported by Lavanya and Chandramohan (2003) [9]. Looking to the significance of both types of gene action in the expression of different traits, it is suggested that bi-parental mating with reciprocal recurrent selection should be employed so that additive as well as non additive gene action could be exploited simultaneously for population improvement.

The variance components due to males were higher than those of females for days to maturity of primary spike, total length of primary spike, effective length of primary spike, number of effective spikes per plant, number of capsule in primary spike, 100-seed weight and seed yield per plant. Similar results were obtained by Dube *et al.* (2018) [4] for effective primary spike length, number of capsule per primary spike, and seed yield per plot. The females contributed largely for total genetic variance for days to 50% flowering of primary raceme, plant height up to primary spike and number of nodes up to primary spike in comparison to males. Similar results were obtained by Dube *et al.* (2018) [4] for days to flowering and number of nodes up to primary spike.

The estimate of GCA effect indicated that the parents DPC-23, DCS-64, DCS-102 and DCS-105 were good general combiners for earliness i.e. for days to 50% flowering of primary raceme, days to maturity of primary spike, plant height up to primary spike and number of nodes to primary spike(Table 2a, Table 3 and Table 4). Good general combiners for these traits were also reported by Panera *et al.* (2018) [12]. Out of these four genotypes, DPC-23, DCS-64 and DCS-102 were early in per se performance with respect to days to 50% flowering of primary raceme and days to maturity of primary spike (Table 4). Parental lines M-571, DCS-108, DCS-109, DCS-110 and DCS-119 were good combiners for total length of primary spike and effective length of primary spike out of which M-571, DCS-109 and DCS-110 were having high per se performance with respect to these two traits. The genotypes M-571, DCS-110 and DCS-112 were found to be good combiners for characters like number of capsules in primary spike, 100-seed weight and seed yield per plant. The estimate of GCA effect indicated that the parents M-571, DCS-110, DCS-112 and DCS-86 were good general combiners for seed yield per plant and some of the yield attributing characters.

The information on best performing parents and hybrids, top ranking good general combiners, heterobeltiotic hybrids and good specific combiners are presented in Table 4. The estimates of SCA effects revealed that none of the crosses were consistently superior for all the traits (Table 2b). Out of 24 hybrids studied, two cross combinations (DPC-23 x DCS-123 and M-571 x DCS-105) exhibited significant and positive SCA effects for seed yield per plant (Table 2b and Table 4). Four hybrids *viz*. M-571 x DCS-110 (102.8g), M-571 x DCS-112 (100.6g), M-571 x DCS-105 (93.8g) and DPC-23 x DCS-110 (93.4g) had high per se performance along with significant positive heterobeltiosis and standard heterosis for seed yield per plant (Table 5). The next best hybrid was DPC-23 x DCS-123 (91.11g) with positive and significant heterobeltiosis and also having more than 10% standard heterosis for seed yield per plant. The first two high yielding hybrids M-571 x DCS-110 and M-571 x DCS-112 were having average and positive SCA effect for seed yield per plant involving good x good general combiner parents for the trait. Singh and Yadav (1981) [17], Mehta (2000) [10] and Tank et al. (2003) [19] reported that two good combiners may not always result in high SCA effect. The hybrid M-571 x DCS-110 also showed significant and desirable SCA effects for days to 50% flowering of primary raceme, days to maturity of primary spike, plant height up to primary spike, number of nodes up to primary spike and 100-seed weight (Table 4 and Table 5). Similarly, M-571 x DCS-112 recorded significant and desirable SCA effect for days to maturity of primary spike and number of capsules in primary spike. The hybrid M-571 x DCS-105 ranked 3rd in per se performance with respect to seed yield per plant which involved good x average combiner parents for seed yield. It recorded significant positive SCA effect with respect to seed yield per plant and desirable significant SCA effect for total length of primary spike, effective length of primary spike, number of capsules in primary spike and 100-seed weight. The 4th ranking hybrid DPC-23 x DCS-110 exhibited average SCA effect with respect to seed yield per plant with poor x good combiners for this trait. It also recorded significant positive SCA effect for number of capsules in primary spike. Similarly DPC-23 x DCS-123 ranked 5th in per se performance for seed yield per plant with significant positive SCA effect and poor x average combiners for the trait. It exhibited significant and desirable SCA effect for number of nodes up to primary spike and number of effective spikes/plant. In general, hybrids with significant SCA effect for seed yield also recorded significant and desirable SCA effect for one or more of its component traits. Similar findings were also reported by Kasture *et al.* (2014) [7], Patel *et al.* 2017 [14] and Jalu *et al* (2017) [6]. The involvement of at least one good general combiner for expression of desirable SCA effect in hybrids was also reported by Golakia *et al.* (2008) [5], Lavanya and Chandramohan (2003) [9], Barad *et al.* (2009) [1] and Ramesh *et al.* (2013) [16].

A comparison of per se performance of hybrids and their SCA effect (Table 2b and Table 4) revealed that per se performance of crosses are not related with their SCA effect in majority of the characters. Similar results have been reported by Dobariya *et al*. (1992) [3] and Mehta (2000) [10]. This may be due to the fact that per se performance is a realized value, whereas, SCA effect is an estimate, measured as the deviation of F_1 over parental performance. It is therefore more desirable to select crosses based on the per se performance rather than considering magnitude of SCA effects alone. High SCA effects due to good x good combiners reflect additive x additive type of gene interaction and superiority of favourable genes contributed by the parents. In fact, in most of the cross combinations the best specific combinations for different characters involved either good x good, good x poor, average x average and average x poor general combiners. It indicated additive x dominance type of gene interaction, which could produce desirable types of transgressive segregants in subsequent generations. This suggested that information on GCA effects should be supplemented by SCA effects and hybrid performance to predict the possibility of occurrence of transgressive types in segregating generations.

Table 1: Pooled analysis of variance for combining ability over three years for different characters in castor(2014-15 to 2016-17)

Source	df	DFF	DM	PH	NN
Females (Gi.)	1	2065.85 **	2197.78 **	19611.98 **	511.53 **
Males (G.j)	11	154.27 *	576.85 *	1025.20 *	26.73 **
Females x Males (Sij)	11	37.42 **	190.17 **	305.34 **	4.79 **
Environments (E)	2	52.42 **	929.59 **	9077.24 **	88.93 **
Females x Environment (Gi. X E)	2	1.39	176.17 **	616.07 **	8.68 **
Males x Environment (G.j x E)	22	14.76 *	23.01	152.62 **	2.10
Females x Males x E (Sij x E)	22	6.34 **	17.22 **	43.90	1.32 **
Error	138	1.93	5.01	30.73	0.59
Variance components					
Females (σ^2gi.)		19.11	20.30	181.32	4.73
Males (σ^2g.j)		8.46	31.76	55.30	1.45
Females x Males (σ^2Sij)		3.94	20.55	30.61	0.47
Females x Environment (σ^2gi. x e)		-0.02	4.75	16.28	0.22
Males x Environment (σ^2g.j x e))		2.13	2.97	20.46	0.26
Females x males x Envt. (σ^2Sij x e)		1.45	4.01	4.69	0.25

σ^2GCA		17.59	21.94	163.31	4.26
σ^2SCA		3.94	20.55	30.61	0.47
σ^2GCA/ σ^2SCA		4.47	1.07	5.33	9.07

N.B.: DFF- Days to 50% flowering of primary raceme, DM - Days to maturity of primary spike, PH - Plant height up to primary spike, NN - Number of nodes up to primary spike
* Significant at 5% level; ** Significant at 1% level

Table 1: contd.

Source	df	TLPS	ELPS	NES	NCP	100-seed wt.	Seed yield/plant
Females (Gi.)	1	149.67	267.11	0.01	540.23	63.04	1796.89
Males (G.j)	11	223.72	330.29	1.81	268.32	207.75 **	2100.31
Females x Males (Sij)	11	157.83 **	174.45 **	0.94 **	297.39 **	13.84 **	776.93 **
Environments (E)	2	1921.72 **	1895.80 **	3.91 **	2897.66 **	48.19 **	22441.31 **
Females x Environment (Gi. X E)	2	26.50	40.11	0.24	62.93	47.05 **	104.89
Males x Environment (G.j x E)	22	18.80	19.20	0.37	66.04	5.02 *	300.37
Females x Males x E (Sij x E)	22	27.20 *	24.53 *	0.29 *	50.18 **	2.32 **	187.90
Error	138	14.17	12.98	0.16	19.22	0.74	147.82
Variance components							
Females (σ^2gi.)		1.27	2.37	-0.001	4.85	0.58	15.47
Males (σ^2g.j)		11.73	17.70	0.09	13.99	11.50	109.65
Females x Males (σ^2Sij)		16.15	18.09	0.09	31.22	1.46	72.27
Females x Environment (σ^2gi. x e)		0.39	0.79	0.003	1.29	1.29	-0.60
Males x Environment (σ^2g.j x e))		1.05	1.26	0.04	8.27	0.73	28.97
Females x males x Envt. (σ^2Sij x e)		4.90	4.31	0.05	11.25	0.55	20.46
σ^2GCA		2.76	4.56	0.01	6.16	2.14	28.92
σ^2SCA		16.15	18.09	0.09	31.22	1.46	72.27
σ^2GCA/ σ^2SCA		0.17	0.25	0.13	0.20	1.46	0.40

N.B.: TLPS - Total length of primary spike, ELPS - Effective length of primary spike, NES - Number of effective spikes/plant, NCP - Number of capsules in primary spike
*Significant at 5% level; ** Significant at 1% level

Table 2a: General combining ability effect of lines and testers (pooled over three years) for ten different characters in castor

Sl. No.	Genotype	Days to 50% flowering of primary raceme	Days to maturity of primary spike	Plant height up to primary spike	Number of nodes up to primary spike	Total length of primary spike	Effective length of primary spike	Number of effective spikes/plant	Number of capsules in primary spike	100-seed weight	Seed yield per plant
Females(Lines)											
1	DPC-23	-3.09**	-3.19**	-9.53**	-1.54**	-0.83*	-1.11**	-0.01	-1.58**	-0.54**	-2.88**
2	M-571	3.09**	3.19**	9.53**	1.54**	0.83*	1.11**	0.01	1.58**	0.54**	2.88**
Males(Testers)											
1	DCS-64	-3.01**	-9.00**	-7.88**	-1.23**	-1.95*	-1.20	0.58**	-4.00**	-6.57**	-16.92**
2	DCS-86	0.32	3.23**	2.20	0.02	-3.12**	-3.54**	0.16	-6.35**	3.43**	8.36**
3	DCS-102	-5.23**	-9.50**	-9.16**	-1.10**	-1.83*	-1.37	0.04	0.73	-3.24**	-16.20**
4	DCS-105	-3.01**	-7.72**	-7.42**	-1.33**	-2.37**	-1.76*	0.31**	-4.92**	-0.85**	-0.31
5	DCS-107	1.82**	1.45**	2.08	1.27**	0.37	1.09	-0.61**	1.64	1.80**	-6.64*
6	DCS-108	-0.51	0.17	-5.51**	-1.16**	4.93**	5.58**	0.33**	3.59**	-5.34**	3.36
7	DCS-109	-2.18**	-0.77	-7.60**	-0.85**	3.35**	3.95**	-0.28**	1.85	1.24**	-0.87
8	DCS-110	-0.12	4.45**	1.23	-0.55**	7.02**	7.76**	-0.07	6.23**	3.70**	19.19**
9	DCS-112	2.16**	3.78**	0.91	0.29	-3.06**	-3.07**	0.01	4.48**	2.30**	14.13**
10	DCS-118	1.82**	2.50**	9.52**	1.00**	-2.36**	-3.77**	-0.24**	-1.80	-0.55**	-6.20*
11	DCS-119	3.27**	7.00**	11.60**	1.52**	2.13*	2.88**	-0.11	-1.36	2.07**	0.91
12	DCS-123	4.66**	4.39**	10.03**	2.12**	-3.12**	-6.55**	-0.11	-0.09	2.01**	1.19

* Significant at 5% level; ** Significant at 1% level

Table 2b: Specific combining ability effect of hybrids (pooled over three years) for ten different characters in castor

Sl. No.	Hybrids/Cross combinations	Days to 50% flowering of primary raceme	Days to maturity of primary spike	Plant height up to primary spike	Number of nodes up to primary spike	Total length of primary spike	Effective length of primary spike	Number of effective spikes/plant	Number of capsules in primary spike	100-seed weight	Seed yield per plant
1	DPC-23 x DCS-64	-1.02*	-4.14**	8.13**	0.77**	1.73	2.01	-0.24	1.85	1.88**	6.33
2	DPC-23 x DCS-86	-1.24**	0.30	-3.22	-0.52*	0.49	-0.39	0.33**	-3.77**	-0.16	2.50
3	DPC-23 x DCS-102	0.09	-3.09**	-4.35*	-0.66**	-3.27**	-3.20**	-0.10	-3.07*	0.51	-2.06
4	DPC-23 x DCS-105	-1.91**	-5.20**	-5.53**	-0.59*	-5.16**	-5.01**	0.21	-7.16**	-1.54**	-12.28**
5	DPC-23 x DCS-107	0.70	5.52**	2.42	0.21	3.42**	3.68**	-0.02	2.66	0.77**	4.05
6	DPC-23 x DCS-108	-0.30	-0.20	-3.15	0.04	-3.48**	-3.30**	0.16	-4.25**	0.59*	0.83
7	DPC-23 x DCS-109	-1.30**	-1.14	2.94	0.42	-0.63	-0.21	-0.27*	2.45	-0.39	-6.17
8	DPC-23 x DCS-110	1.98**	2.97**	4.60*	0.56*	0.68	0.96	0.05	3.91**	-0.75**	-1.78

9	DPC-23 x DCS-112	-0.63	3.63**	1.14	-0.01	-1.67	-2.14	-0.14	-3.43*	-0.08	-4.62
10	DPC-23 x DCS-118	0.37	-0.75	-1.96	-0.27	2.30	3.36**	-0.09	3.60**	-0.28	0.27
11	DPC-23 x DCS-119	3.15**	2.75**	1.67	0.61*	4.74**	5.02**	-0.28*	5.35**	-0.70*	-0.95
12	DPC-23 x DCS-123	0.09	-0.64	-2.69	-0.55*	0.84	-0.78	0.39**	1.87	0.15	13.88**
13	M-571 x DCS-64	1.02*	4.14**	-8.13**	-0.77**	-1.73	-2.01	0.24	-1.85	-1.88**	-6.33
14	M-571 x DCS-86	1.24**	-0.30	3.22	0.52*	-0.49	0.39	-0.33**	3.77**	0.16	-2.50
15	M-571 x DCS-102	-0.09	3.09**	4.35*	0.66**	3.27**	3.20**	0.10	3.07*	-0.51	2.06
16	M-571 x DCS-105	1.91**	5.20**	5.53**	0.59*	5.16**	5.01**	-0.21	7.16**	1.54**	12.28**
17	M-571 x DCS-107	-0.70	-5.52**	-2.42	-0.21	-3.42**	-3.68**	0.02	-2.66	-0.77**	-4.05
18	M-571 x DCS-108	0.30	0.20	3.15	-0.04	3.48**	3.30**	-0.16	4.25**	-0.59*	-0.83
19	M-571 x DCS-109	1.30**	1.14	-2.94	-0.42	0.63	0.21	0.27*	-2.45	0.39	6.17
20	M-571 x DCS-110	-1.98**	-2.97**	-4.60*	-0.56*	-0.68	-0.96	-0.05	-3.91**	0.75**	1.78
21	M-571 x DCS-112	0.63	-3.63**	-1.14	0.01	1.67	2.14	0.14	3.43*	0.08	4.62
22	M-571 x DCS-118	-0.37	0.75	1.96	0.27	-2.30	-3.36**	0.09	-3.60**	0.28	-0.27
23	M-571 x DCS-119	-3.15**	-2.75**	-1.67	-0.61*	-4.74**	-5.02**	0.28*	-5.35**	0.70*	0.95
24	M-571 x DCS-123	-0.09	0.64	2.69	0.55*	-0.84	0.78	-0.39**	-1.87	-0.15	-13.88**

* Significant at 5% level; ** Significant at 1% level

Table 3: Performance of parents for general combining ability effects over environments for ten different characters

Sl. No.	Genotype	Days to 50% flowering of primary raceme	Days to maturity of primary spike	Plant height up to primary spike (cm)	Number of nodes up to primary spike	Total length of primary spike	Effective length of primary spike	Number of effective spikes/plant	Number of capsules in primary spike	100-seed weight	Seed yield per plant
Females(Lines)											
1	DPC-23	-G	-G	-G	-G	-P	-P	-A	-P	-P	-P
2	M-571	P	P	P	P	G	G	A	G	G	G
Males(Testers)											
1	DCS-64	-G	-G	-G	-G	-P	-A	G	-P	-P	-P
2	DCS-86	A	P	A	A	-P	-P	A	-P	G	G
3	DCS-102	-G	-G	-G	-G	-P	-A	A	A	-P	-P
4	DCS-105	-G	-G	-G	-G	-P	-P	G	-P	-P	-A
5	DCS-107	P	P	A	P	A	A	-P	A	G	-P
6	DCS-108	-A	A	-G	-G	G	G	G	G	-P	A
7	DCS-109	-G	-A	-G	-G	G	G	-P	A	G	-A
8	DCS-110	-A	P	A	-G	G	G	-A	G	G	G
9	DCS-112	P	P	A	A	-P	-P	A	G	G	G
10	DCS-118	P	P	P	P	-P	-P	-P	-A	-P	-P
11	DCS-119	P	P	P	P	G	G	-A	-A	G	A
12	DCS-123	P	P	P	P	-P	-P	-A	-A	G	A

Note: G = Good combiner; A = Average combiner; P = Poor combiner; - = Negative value

Table 4: Summary table showing the best parents in *per se* and GCA effect and crosses in *per se*, heterobeltiosis and SCA effect over environments for various characters in castor

Sl. No.	Characters	Best performing parents (*per se*)	Best general combiners	Best performing crosses (*per se*)	Best heterobeltiotic crosses	Best specific combiners
1	Days to 50% flowering of primary raceme	DPC-23 DCS-64 DCS-102 DCS-108	DPC-23 DCS-102 DCS-64 DCS-105 DCS-109	DPC-23 x DCS-102 DPC-23 x DCS-105 DPC-23 x DCS-64 DPC-23 x DCS-109 DPC-23 x DCS-108	DPC-23 x DCS-123 DPC-23 x DCS-86 M-571 x DCS-102 DPC-23 x DCS-105 DPC-23 x DCS-109	M-571 x DCS-119 M-571 x DCS-110 DPC-23 x DCS-105 DPC-23 x DCS-109 DPC-23 x DCS-86
2	Days to maturity of primary spike	DPC-23 DCS-64 DCS-102 DCS-108	DPC-23 DCS-102 DCS-64 DCS-105	DPC-23 xa DCS-64 DPC-23 x DCS-105 DPC-23 x DCS-102 DPC-23 x DCS-109 DPC-23 x DCS-108	DPC-23 x DCS-123 DPC-23 x DCS-105 M-571 x DCS-123 DPC-23 x DCS-102 DPC-23 x DCS-64	M-571 x DCS-107 DPC-23 x DCS-105 DPC-23 x DCS-64 M-571 x DCS-112 DPC-23 x DCS-102 M-571 x DCS-110
3	Plant height up to primary spike	DPC-23 M-571 DCS-108 DCS-102 DCS-110	DPC-23 DCS-102 DCS-64 DCS-109 DCS-105	DPC-23 x DCS-102 DPC-23 x DCS-105 DPC-23 x DCS-108 DPC-23 x DCS-109 DPC-23 x DCS-86	DPC-23 x DCS-105 DPC-23 x DCS-86 DPC-23 x DCS-123 DPC-23 x DCS-110 DPC-23 x DCS-118	M-571 x DCS-64 DPC-23 x DCS-105 M-571 x DCS-110 DPC-23 x DCS-102 DPC-23 x DCS-86
4	Number of nodes up to primary spike	DPC-23 DCS-64 DCS-108 DCS-110 DCS-109	DPC-23 DCS-105 DCS-64 DCS-108 DCS-102	DPC-23 x DCS-105 DPC-23 x DCS-102 DPC-23 x DCS-108 DPC-23 x DCS-86 DPC-23 x DCS-64	DPC-23 x DCS-123 DPC-23 x DCS-86 DPC-23 x DCS-105 DPC-23 x DCS-112 M-571 x DCS-64	M-571 x DCS-64 DPC-23 x DCS-102 M-571 x DCS-119 DPC-23 x DCS-105 M-571 x DCS-110 DPC-23 x DCS-123

Table 4: Contd…

Sl. No.	Characters	Best performing parents (*per se*)	Best general combiners	Best performing crosses (*per se*)	Best heterobeltiotic crosses	Best specific combiners
5	Total length of primary spike	M-571 DCS-109 DCS-110 DCS-105 DCS-102	M-571 DCS-110 DCS-108 DCS-109 DCS-119	M-571 x DCS-108 M-571 x DCS-110 DPC-23 x DCS-110 DPC-23 x DCS-119 M-571 x DCS-109	DPC-23 x DCS-119 DPC-23 x DCS-107 M-571 x DCS-108 DPC-23 x DCS-108 DPC-23 x DCS-118	M-571 x DCS-105 DPC-23 x DCS-119 M-571 x DCS-108 DPC-23 x DCS-107 M-571 x DCS-102
6	Effective length of primary spike	M-571 DCS-109 DCS-110 DCS-105 DCS-102	M-571 DCS-110 DCS-108 DCS-109 DCS-119	M-571 x DCS-108 M-571 x DCS-110 DPC-23 x DCS-110 DPC-23 x DCS-119 M-571 x DCS-109	DPC-23 x DCS-119 M-571 x DCS-108 DPC-23 x DCS-107 DPC-23 x DCS-108 DPC-23 x DCS-64	DPC-23 x DCS-119 M-571 x DCS-105 DPC-23 x DCS-107 DPC-23 x DCS-118 M-571 x DCS-108
7	Number of effective spikes/plant	DPC-23 DCS-64 DCS-86 DCS-105 DCS-102	DCS-64 DCS-108 DCS-105	M-571 x DCS-64 DPC-23 x DCS-105 DPC-23 x DCS-86 DPC-23 x DCS-108 DPC-23 x DCS-64	M-571 x DCS-119 M-571 x DCS-112 M-571 x DCS-102	DPC-23 x DCS-123 DPC-23 x DCS-86 M-571 x DCS-119 M-571 x DCS-109
8	Number of capsules in primary spike	M-571 DCS-109 DCS-102 DCS-110 DCS-123	M-571 DCS-110 DCS-112 DCS-108	M-571 x DCS-112 M-571 x DCS-108 DPC-23 x DCS-110 M-571 x DCS-102 M-571 x DCS-110	M-571 x DCS-112 M-571 x DCS-108 DPC-23 x DCS-119 DPC-23 x DCS-107 DPC-23 x DCS-118	M-571 x DCS-105 DPC-23 x DCS-119 M-571 x DCS-108 DPC-23 x DCS-110 M-571 x DCS-86 M-571 x DCS-112

Table 4: Contd.

Sl. No.	Characters	Best performing parents (*per se*)	Best general combiners	Best performing crosses (*per se*)	Best heterobeltiotic crosses	Best specific combiners
9	100- seed weight	M-571 DCS-123 DCS-86 DCS-107 DCS-112	M-571 DCS-110 DCS-86 DCS-112 DCS-119	M-571 x DCS-110 M-571 x DCS-86 M-571 x DCS-119 M-571 x DCS-112 DPC-23 x DCS-86	M-571 x DCS-110 DPC-23 x DCS-118 M-571 x DCS-119 DPC-23 x DCS-110 M-571 x DCS-112	DPC-23 x DCS-64 M-571 x DCS-105 DPC-23 x DCS-107 M-571 x DCS-110 M-571 x DCS-119
10	Seed yield per plant	M-571 DCS-102 DCS-110 DCS-105 DCS-109	M-571 DCS-110 DCS-112 DCS-86	M-571 x DCS-110 M-571 x DCS-112 M-571 x DCS-105 DPC-23 x DCS-110 DPC-23 x DCS-123	M-571 x DCS-110 M-571 x DCS-112 DPC-23 x DCS-123 DPC-23 x DCS-110 DPC-23 x DCS-86 DPC-23 x DCS-112 M-571 x DCS-105	DPC-23 x DCS-123 M-571 x DCS-105

Table 5: Performance of best five hybrids (pooled over three years)

Sl. No.	Cross combination (Hybrid)	Seed yield/plant(g) per se	Seed yield per plant				Significant and desirable sca effects for component traits
			H_1	H_2	SCA Effect	Hybrid in relation to GCA of parents	
1	M-571 x DCS-110	102.78	31.58 **	24.33 **	1.78	G x G	Days to 50% flowering of primary raceme, Days to maturity of primary spike, Number of nodes to primary spike, Plant height upto primary spike, 100 seed weight
2	M-571 x DCS-112	100.56	28.73 **	21.64 **	4.62	G x G	Days to maturity of primary spike, Number of capsules in primary spike
3	M-571 x DCS-105	93.78	20.06 **	13.44 *	12.88**	G x A	Total length of primary spike, Effective length of primary spike, Number of capsules in primary spike, 100-seed weight
4	DPC-23 x DCS-110	93.44	24.04 **	13.04 *	-1.78	P x G	Number of capsules in primary spike
5	DPC-23 x DCS-123	91.11	28.53 **	10.22	13.88**	P x A	Number of nodes to primary spike, Number of effective spikes per plant
	DCH-177(Check)	82.67					

NB: H_1 = Heterobeltiosis; H_2 = Heterosis over best check 'DCH-177'
* Significant at 5% level; ** Significant at 1% level

Conclusion

The parental lines DPC-23, DCS-64, DCS-102 and DCS-105 were good general combiners for earliness; M-571, DCS-108, DCS-109, DCS-110 and DCS-119 were good combiners for total length of primary spike and effective length of primary spike and the genotypes M-571, DCS-110 and DCS-112 were good combiners for characters like number of capsules in primary spike, 100-seed weight and seed yield per plant. These parental lines can be utilized in hybridization programme for improvement of the respective characters.

None of the crosses exhibited consistently high SCA effects for all the characters studied. Crosses showing high SCA effects for seed yield also recorded high SCA effects for one or more of yield components. The cross exhibiting high SCA effects did not always involve parents with high GCA effects suggesting that the interallelic interactions were also important for the characters. The *per se* performance of hybrids for various traits are not always related with their SCA effects. From results of combining ability, gene action and component of variance, it is concluded that non-additive gene action was predominant for total length of primary spike, effective length of primary spike, number of effective spikes per plant, number of capsules in primary spike and seed yield per plant which indicated that heterosis breeding would be helpful for improving these traits. Two cross combinations *viz*., DPC-23 x DCS-123 and M-571 x DCS-105 manifested high and desirable SCA effect for seed yield per plant and for one or more component traits. Besides these two hybrids, other three hybrids *viz*. M-571 x DCS-110, M-571 x DCS-112 and DPC-23 x DCS-110 were better in per se performance and heterosis with respect to seed yield per plant and also exhibited significant SCA effects for one or more component traits.

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