Identification of superior parents and hybrids for yield improvement in castor (*Ricinus communis* L.)

YAMANURA, R MOHAN KUMAR, C LAVANYA[1] AND S SENTHILVEL[1]

AICRP on Castor, ZARS, University of Agricultural Sciences, GKVK, Bengaluru-560 065, Karnataka

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ABSTRACT

An experiment was conducted to determine the nature and magnitude of heterosis in castor for seed yield and its yield attributing traits. Forty hybrids were synthesized involving five lines and eight testers through line x tester (L×T) mating design and were evaluated for yield and its components. Among 13 parental lines, JP-96, VP-1, DPC-9, RG-2661-1, RG-109 and RG-3160 were identified as good general combiners for seed yield and its components, which can be directly exploited in heterosis breeding. The cross combination, DPC-18 × RG-2661-1 was good specific combiner for early maturity. High seed yield per plant was recorded for hybrids: VP-1×RG-109 (105.04 g), DPC-18×RG-1771 (98.26g) and DPC-18×RG-2661-1 (97.97 g). These promising crosses involved parents with high × high and high × low GCA effects and were found promising for high yield potential in castor.

Keywords: Castor, Combining ability, Heterosis, Gene action, Standard heterosis

Castor (*Ricinus communis* L.) is one of the most important non-edible oilseed crops of tropical, sub-tropical and warm temperate parts of the world (Weiss, 2000). It is cultivated in several countries; India, Brazil, China, Russia, Thailand and Philippines are the major castor growing countries. India is the world leader in castor area (7.62 lakh ha), production (12.2 lakh tonnes) and productivity (1600 kg/ha) (ICAR-IIOR, 2020). The seeds of castor contain about 40 to 60 per cent oil rich in ricinolein an unusual fatty acid found only in castor. The castor oil has great industrial value as it is used for the manufacturing of soaps, refined and perfumed hair oil, printing inks, varnishes, synthetic resins, carbon paper, lubricant, ointments, cosmetics and processed leather. Castor is largely grown as a rainfed crop and the seed yield is affected due to vagaries of the climatic factors which in turn influence crop traits including sex expression (Aher *et al.*, 2015). It is a highly cross-pollinated species with a complex sex mechanism that is influenced by environment (Lavanya *et al.*, 2006). Therefore, development of hybrids with high femaleness is needed to exploit the heterosis effectively.

With the availability of complete pistillate lines, exploitation of hybrid vigour commercially has become feasible and economical in castor (Lavanya *et al.*, 2006). The *per se* performance of parental lines provides clues about hybrid performance; however, information on magnitude of heterosis and combining ability of parents for yield and its component traits would aid in selecting appropriate parents and desirable cross combinations.

Similarly, information on type of gene action for different traits is important in formulating an appropriate breeding programme for yield improvement. Heterosis for various agronomic traits has been reported in castor (Dangaria *et al.*, 1987; Ramesh *et al.*, 2013; Aher *et al.*, 2015; Patel *et al.*, 2015; Sapovadiya *et al.*, 2015). Line × Tester (L × T) analysis suggested by Kempthorne (1957) is widely used to study gene action and combining ability among parents for different traits. In this context, the present investigation was carried out in castor with the twin objectives of estimating the magnitude of heterosis for seed yield and its component traits and to identify the superior parents and hybrid combinations for commercial exploitation.

MATERIALS AND METHODS

The investigation was conducted during *kharif* 2018 at Zonal Agricultural Research Station (All India Coordinated Research Project, AICRP-Castor), University of Agricultural Sciences, GKVK, Bengaluru. The materials were obtained from the ICAR-Indian Institute of Oilseeds Research (ICAR-IIOR), Hyderabad and Castor and Mustard Research Station (AICRP-Castor), Sardar Krushinagar Dantiwada Agricultural University, Gujarat, India. Five pistillate lines (VP-1, JP-96, M-574, DPC-18 and DPC-9) and eight testers (RG-43, RG-1771, RG-109, RG-2661-1, RG-392, RG-72, RG-3160 and RG-1608) were crossed using L ×T mating design and the 40 experimental hybrids were generated during *kharif* 2018-2019. Thus, the experimental materials consisted of 56 entries including 5 lines, 8 testers, 40 hybrids and 3 checks (DCH-177, DCS-9 and DCS-107). While crossing work, racemes of the female parents were bagged before opening of the flower. In the male parents all opened flowers in the spike were removed prior to bagging in order to obtain pure pollen for pollination. At the time when stigma became receptive, the pollen collected in a labelled Petri

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[1]ICAR-Indian Institute of Oilseeds Research, Hyderabad-500 030, Telangana; Corresponding author's E-mail: yaman3181aug8@gmail.com

plate from the desired male parents were dusted over the stigma of the female parents; stigma remains receptive after anthesis for a period of 5 to 10 days and blooming continues up to 21 days. After pollination, the female parent spikes were bagged and labelled. The dusting of pollen was repeated three to four times every alternate day to ensure sufficient seed setting.

In the succeeding *kharif* 2019-20, the complete set of 56 entries was sown in a Randomized Complete Block Design (RCBD) with two replications. Each entry was planted in a single row of 6.0 meter with the spacing of 90 cm x 60 cm. All the recommended agronomic practices including 40:40:20 kg $N:P_2O_5:K_2O$ per ha were followed. Prophylactic spray of thiodicarb @ 1g/l and propiconazole @ 0.5 ml/l were taken up to manage capsule borer and gray mold disease respectively. Observations were recorded on five randomly selected plants for nine traits *viz*., days to maturity of primary spike (DMPS), number of nodes up to primary spike (NNPS), effective length of primary spike in cm (ELPS), number of capsules on primary spike (NCPS), number of effective spikes per plant (NESPP), 100 seed weight in g (HSW), volume weight in g (VW), seed yield per plant in g (SYPP) and oil content in % (OC). The observations on days to maturity were recorded plot basis. The data were subjected to analysis of variance (ANOVA) and predictability ratio of the lines and testers performance as per the L × T model given by Singh and Chaudhary (1977) using statistical package, Windostat Version 9.3 from Indostat services, Hyderabad (India).

The variance due to general combining ability (GCA) and specific combining ability (SCA) for nine traits was analyzed to find out the gene action among them. Sprague and Tatum (1942) defined GCA as the average performance of a parental line in a series of hybrid combinations and SCA as the performance of the parental lines in a specific hybrid combination. The parents showing high average combining ability in crosses are considered to have good GCA while if their potential to combine well is confined to a particular cross they are considered to have good SCA. From the statistical point of view, the GCA is the main effect and the SCA is an interaction effect. The GCA reflects additive and additive × additive interaction effect. The SCA reflects dominance, additive × dominance and dominance × dominance interaction effects (Fasahat *et al*., 2016).

Degree of dominance is defined as follows. The genetic value of the heterozygote = the mean of the genetic values of the corresponding two homozygotes + the degree of dominance X half the difference between the genetic values of the better homozygote and the worse homozygote. No dominance corresponds to a degree of 0, partial to a degree between 0 and 1, complete dominance to a degree of 1 and overdominance to a degree larger than 1. Positive as well as negative degrees may exist. The average degree of dominance is estimated as the square root of the average squared degree of dominance (Lagerval, 1961).

RESULTS AND DISCUSSION

The ANOVA results showed that the mean squares (MS) due to genotypes were significant for all the traits studied. The MS due to genotypes were further partitioned into parents, hybrids and parents vs. hybrids. The parents differed significantly for all the traits except volume weight (VW). The hybrids differed significantly for all the traits except Effective length of primary spike (ELPS) and VW, which indicated that considerable genetic variability was present among the parents and hybrids (Table 1). The ANOVA results further revealed that the MS due to parents vs. hybrids were significant for all the traits, indicating the possibility of heterotic effects (Table 1).

The ANOVA for combining ability revealed that MS due to the hybrids were significant for all the traits except VW. The MS due to the females were significant for all traits except number of nodes upto primary spike (NNPS), number of effective spikes per plant (NESPP) and seed yield per plant (SYPP) whereas the males were significant for ELPS. The MS due to L × T interaction were significant for all the traits except ELPS, hundred seed weight (HSW) and VW. This suggests that the variation for seed yield in hybrids may be strongly influenced by the L × T interaction effects. The magnitude of MS due to the lines was larger for most traits than the testers indicating that the lines were diverse than the testers (Table 2).

The MS due to GCA and GCA effects indicated the involvement of both additive and non-additive gene action in determining the yield traits. The MS due to L × T interactions were highly significant for seed yield and its components, which indicated the importance of SCA variance. Similar results were reported by Chaudhari *et al*. (2011), Ramesh *et al*. (2013), Rajani *et al*. (2015), Patel *et al*. (2015), Patted *et al*. (2016), Punewar *et al*. (2017) and Delvadiya *et al*. (2018).

Higher SCA variance than GCA variance for all the traits indicated the predominance of non-additive gene action. The ratio between GCA and SCA variances was highest for ELPS (0.12) and VW (0.12) followed by DMPS (0.09), NCPS (0.07), NNPS (0.07) HSW and OC (0.06). The ratio was less than one in all the traits, which indicates the predominance of non-additive gene action. The degree of dominance was more than one for days to maturity for primary spike (DMPS), NNPS, NESPP and SYPP which indicates over dominance whereas for the other traits the value ranged between 0 to 1 indicating partial dominance. Therefore, these traits could be improved through heterosis breeding (Table 3). The above findings are in agreement with the earlier reports of Ramesh *et al*. (2000), Kavani *et al*. (2001), Ramu *et al*. (2002),Thakker *et al*. (2005) and Tank *et al*. (2003). Dominant gene action for seed yield in castor was reported earlier by several researchers (Ramu *et al*., 2002; Lavanya and Chandramohan, 2003; Tank *et al.,* 2003; Solanki *et al.,* 2004; Thakker *et al.,* 2005; Venkataramana *et al.,* 2005; Solanki, 2006; Chaudhari *et al.,* 2011; Ramesh *et al.,* 2013; Rajani *et al.,* 2015; Patel *et al.,* 2015; Patted *et al.,* 2016; Panewar *et al.,* 2017; Delvadiya *et al.,* 2018).

Table 1 Analysis of variance (mean squares) for yield and its components

Source of Variation	Df	Days to maturity of primary spike	Number of nodes up to primary spike	Effective length of primary spike (cm)	Number of capsules on primary spike	Number of effective spikes per plant	100 seed weight (g)	Volume weight (g)	Seed yield per plant (g)	Oil content (%)
Replicates	1	14.35	0.53	7.97	17.61	0.27	1.86	14.42	80.25	1.39
Genotypes	52	109.51**	1.53**	84.54**	273.64**	5.11**	15.35**	51.64*	1124.94**	6.53**
Parents	12	129.26**	1.33**	146.90**	436.36**	4.96**	12.77*	44.73	1298.57**	11.05**
Parents (Line)	4	35.25**	0.12	54.22	93.60	9.46**	5.34	33.37	1263.68**	24.15**
Parents (Testers)	7	156.82**	2.01**	47.00	175.96**	1.31	18.47*	56.73	950.16**	4.35**
Parents (L vs T)	1	312.40**	1.38	1216.93**	3630.20**	12.54**	2.60	6.21	3876.98**	5.52*
Parents vs Hybrids	1	56.52**	8.03**	1089.40**	2561.40**	46.89**	90.68**	505.88**	3417.70**	127.69**
Hybrids	39	104.79**	1.42**	39.58	164.92**	4.09**	14.21**	42.12	1012.72**	2.03**
Line Effect	4	427.88**	2.49	132.03**	524.51**	9.63	55.40**	102.93*	2227.72	6.08*
Tester Effect	7	31.35	2.12	64.85*	115.30	0.96	15.55	48.73	735.29	1.69
Line * Tester Eff.	28	76.99**	1.09**	20.06	125.95**	4.08**	7.99	31.78	908.51**	1.54*
Error	52	4.06	0.40	39.12	54.65	1.14	6.16	28.24	178.97	0.89

Table 2 Analysis of variance and estimates of combining ability for yield and its components

Source of Variation	Df	Days to maturity of primary Spike	Number of nodes up to primary spike	Effective length of primary spike (cm)	Number of capsules on primary spike	Number of effective spikes per plant	100 seed weight (g)	100 volume Weight (g)	Seed yield per plant (g)	Oil content (%)
Replicates	1	19.01*	0.11	129.03 **	4.58	0.217	0.57	55.58	1.31	0.11
Crosses	39	104.79**	1.42**	39.58 **	164.99 **	4.09 **	14.21 **	42.12	1012.72 **	2.03 **
Line Effect	4	427.88**	2.49	132.03 **	524.51 **	9.64	55.40 **	102.93 *	2227.72	6.08 *
Tester Effect	7	31.36	2.12	64.85 *	115.30	0.96	15.56	48.73	735.29	1.69
Line *Tester Eff.	28	76.99**	1.10 **	20.06	125.95 **	4.08 **	7.80	31.78	908.51 **	1.54 *
Error	39	3.94	0.35	14.99	54.56	1.39	6.03	32.37	154.28	0.69

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

Table 3 Estimates of GCA and SCA variances, degrees of dominance and % contribution of Lines, Testers and Lines x Testers to crosses in castor

Traits	GCA	SCA	GCA/ SCA Ratio	Degree of Dominance	Lines	Testers	Lines x Testers
Days to maturity of primary spike	21.39	215.57	0.09	1.03	41.87	5.37	52.75
Number of nodes up to primary spike	0.12	1.71	0.07	1.09	17.94	26.73	55.33
Effective length of primary spike(cm)	6.60	56.16	0.12	1.02	34.21	29.41	36.38
Number of capsules on primary spike	26.23	352.66	0.07	0.94	32.62	12.55	54.83
Number of effective spikes per plant	0.48	11.42	0.04	1.52	24.15	4.21	71.64
100 seed weight(g)	5.15	88.98	0.06	0.45	40.36	19.65	39.98
Volume weight(g)	2.77	22.37	0.12	0.49	25.06	20.76	54.17
Seed yield per plant (g)	111.39	2543.83	0.04	1.35	22.56	13.03	64.41
Oil content (%)	0.30	4.30	0.06	0.84	30.72	14.95	54.33

Per cent contribution of line, testers and line x testers to the crosses (Table 3) revealed that the lines contribute more to the performance of the crosses in case of DMPS, ELPS, NCPS, NESP, HSW, VW and oil content (OC) whereas of the testers contribute more to the performance of crosses only in case of NNPS indicating the significant contribution of the female parents in the hybrid performance. The contribution of lines and testers were found equally important for the development of the yield and its attributing characters. This showed that average general combiner could give high heterotic performance and could be effectively used in heterosis breeding programmes. Similar results were also reported by Pandey and Singh (2002), Yamanura *et al.* (2014), Patel *et al.* (2015), Patted *et al.* (2016), Panewar *et al.* (2017) and Delvadiya *et al.* (2018).

Trait-wise estimation of GCA effects of L × T is presented in Table 4. The good general combiners identified for various traits included JP-96, VP-1, DPC-9, RG-2661-1, RG-109 and RG-3160 for seed yield and its components, JP-96, VP-1, RG-43 and RG-1771 for DMPS, M-574, DPC-18, and RG-3160 for NNPS, VP-1 and RG-109 for ELPS, VP-1, DPC-9, RG-2661-1, RG-3160 and RG-392 for NCPS and NESPP, DPC-9 and RG-72 for HSW and VP-1 and RG-43 for VW. Heritability is a good indicator of the transmission of traits from parents to their offspring (Falconer.,1989). High heritability coupled with high GA were observed for the traits *viz.,* DMPS, NCPS, SYPP and ELPS indicating that genotypic variation for the characters could probably be attributed to high additive effect. Moderate GA with high heritability was observed in HSW and VW. Low GA was observed in NNPS, NESPP and OC suggesting that selection for these traits may not be effective. Predictability ratios was high in HSW, VW, OC and NCPS, moderate in DMPS, NNPS, NES/P and SYPP and low or negative in ELPS (Table 4).

Table 4 Estimates of general combining ability effects among of nine quantitative traits in Castor

Traits	Days to maturity of primary spike	Number of nodes up to primary spike	Effective length of primary spike (cm)	Number of capsules on primary spike	Number of effective spikes per plant	100 seed weight (g)	Volume weight (g)	Seed yield/plant (g)	Oil content (%)
LINES									
VP-1	-3.375 **	-0.467 **	4.397 **	4.351 *	0.708 *	-2.592 **	3.156 *	4.970	0.214
JP-96	-7.313 **	-0.142	1.099	-1.718	-0.198	1.120	1.531	12.638 **	0.495
M-574	2.938 **	0.435 **	-0.568	-2.593	-1.239 **	-1.042	-0.321	-18.417 **	-1.036
DPC-18	5.188 **	0.386 *	-2.464	-7.180 **	0.184	0.356	-0.806	4.466	-0.063
DPC-9	2.563 **	-0.212	-2.464	7.140 **	0.545 *	2.160 **	-3.560 *	-3.658	0.390
TESTERS									
RG-43	-3.588 **	-0.805 **	-1.462	-0.221	0.044	-1.696 *	2.790	-2.710	0.018
RG-1771	-1.788 **	-0.207	-1.831	-4.836 *	-0.389	-0.952	-3.374	-0.752	-0.499
RG-109	0.913	0.363	3.737	-2.868	0.267	1.212	2.201	6.654	-0.450
RG-2661-1	1.013	0.327	1.913	4.808 *	0.379	0.276	1.176	13.921 **	0.264
RG-392	0.413	-0.093	-0.898	2.387	0.322	0.910	-1.383	-10.207 *	0.029
RG-72	1.513 *	-0.347	-3.997	-1.670	-0.423	1.855 *	-2.022	1.379	0.609
RG-3160	0.313	0.641 **	2.336	3.898	-0.075	-0.737	1.430	3.869	0.394
RG-1608	1.213	0.118	0.204	-1.501	-0.122	-0.867	-0.818	-12.152 **	-0.368
CD 95% GCA(Line)	1.019	0.320	3.163	3.738	0.540	1.255	2.687	6.765	0.477
CD 95% GCA(Tester)	1.289	0.405	4.001	4.729	0.683	1.588	3.399	8.557	0.603
Heritability (NS) %	47.408	34.821	47.644	39.320	23.853	53.027	31.543	30.610	37.500
Genetic Advance 5 %	8.355	0.658	4.295	8.252	0.804	3.186	3.131	16.134	0.857
Predictability Ratio	0.488	0.457	-22.387	0.534	0.303	0.832	0.805	0.355	0.588

The best three crosses exhibited high SCA along with their *per se* performance, standard heterosis and GCA status of the parents. The data presented in Table 5 indicated that the cross combination, DPC-18 × RG-1771, was a good specific combiner for SYPP and ELPS. The cross combination, DPC-18 × RG-2661-1 was a good specific combiner for early maturity as it showed highly significant negative SCA effect. The early maturing hybrid could be advantageous for rainfed situations because it could escape the terminal drought situation. The crosses, VP-1 × RG-2661-1, DPC-9 × RG-43 and DPC-18 × RG-392 for NNPS, VP-1 × RG-43, DPC-18 × RG-3160 and JP-96 × RG-109 for NCPS, DPC-9 × RG-109, DPC-18 × RG-1608 and M-574 × RG-1771 for HSW, JP-96 × RG-1771, DPC-18 × RG-72 and M-574 × RG-2661-1 were good specific combiners for OC. Similar results of significant SCA effects for yield contributing traits were reported by Solanki and Joshi (2000), Thakker *et al.* (2005), Kanwal *et al.* (2006), Golakia *et al.* (2008), Bard *et al.* (2009), Chandresh (2009), Monapara *et al.* (2010), Sodavadiya *et al.* (2010), Chaudhari *et al.* (2011), Ramesh *et al.* (2013), Rajani *et al.* (2015), Patel *et al.* (2015), Patted *et al.* (2016), Panewar *et al.* (2017) and Delvadiya *et al.* (2018).

The highest seed yield/plant was recorded by the hybrid, VP-1× RG-109 (105.04g) followed by DPC-18×RG-1771 (98.26 g) and DPC-18 × RG-2661-1 (97.97g). These three crosses showing high mean and significant positive SCA effects for seed yield involved the parents with high × high and high × low GCA effects (Table 6). Similar results were reported by Chaudhari *et al.* (2011), Ramesh *et al.* (2013), Rajani *et al.* (2015), Patel *et al.* (2015), Patted *et al.* (2016), Panewar *et al.* (2017) and Delvadiya *et al.* (2018). The better performance of the hybrids involving high × low or low × low general combiners indicated dominance × dominance (epitasis) type of gene action. The crosses showing high SCA effects involving one good general combiner indicated additive × dominance type gene interaction, which exhibited high heterotic performance for yield and yield related traits. The results suggested that the crosses having high mean performance and positive SCA effects for seed yield and related traits had necessarily involved both or at least one parent as good combiner, which could be commercially exploited for hybrid development in castor.

Table 5 Comparison of three best crosses on the basis of specific combining ability effects for different traits

Traits	Crosses	SCA effect	GCA effect and Status			Standard heterosis	*Per se*	Significant SCA effect for other traits
			P1	P2	Status			
Days to maturity of primary Spike	DPC-9 X RG-1608	-10.96**	2.56**	1.21	H×L	-0.57	87.50	-
	DPC-18 X RG-2661-1	-10.39**	5.19**	1.01	H×L	2.84	90.50	DFF
	DPC-9 X RG-3160	-9.06**	2.56**	0.31	H×L	0.57	88.50	-
Number of nodes up to primary spike	VP-1 X RG-2661-1	1.16*	-0.48**	0.33	L×H	11.39*	14.66	-
	DPC-9 X RG-43	1.14*	-0.21	-0.81**	L×L	4.60	13.77	-
	DPC-18 X RG-392	0.72	0.39*	-0.98	H×L	11.39*	14.66	NESPP
Effective length of primary spike (cm)	DPC-9 X RG-43	4.97	-2.46	-1.46	L×L	115.96**	31.67	NN
	VP-1 X RG-72	4.81	4.39**	-3.99	H×L	144.36**	35.83	-
	DPC-18 X RG-1771	4.17	-2.46	-1.83	L×L	107.98**	30.50	SY
Number of capsules on primary spike	VP-1 X RG-43	10.82*	4.35*	-0.22	H×L	218.43**	56.25	-
	DPC-18 X RG-3160	10.31	-7.18**	3.89	L×H	173.59**	48.33	SY
	JP-96 X RG-109	9.12	-1.72	-2.87	L×L	159.47**	45.83	-
Number of effective spikes per plant	DPC-9 X RG-2661-1	2.76**	0.55*	0.38	H×H	308.08**	8.84	SY
	DPC-9 X RG-109	2.31**	0.55*	0.27	H×H	282.45**	8.28	HSW, DFF
	VP-1 X RG-3160	2.11	0.71*	-0.08	H×L	264.90	7.90	-
100 Seed weight (g)	DPC-9 X RG-109	3.61*	2.16**	1.21	H×H	35.35**	39.44	DFF, NES/P
	DPC-18 X RG-1608	2.46	0.36	-0.87	H×L	18.07*	34.41	-
	M-574 X RG-1771	2.10	-1.04	-0.95	L×L	11.75	32.57	DFF, DM
Volume weight (g)	DPC-18 X RG-72	5.52	-0.81	-2.02	L×L	16.60	63.99	DM
	M-574 X RG-72	4.35	-0.32	-2.02	L×L	15.34	63.30	-
	JP-96 X RG-392	4.36	1.53	-1.38	H×L	19.90*	65.80	DM,SY
Seed yield per plant(g)	M-574 X RG-1608	41.17**	-18.42**	-12.15**	L×L	143.65**	71.08	-
	DPC-18 X RG-1771	34.06**	4.47	-0.75	H×L	236.80**	98.26	-
	VP-1 X RG-109	32.94**	4.97	6.65	H×H	260.05**	105.04	-
Oil content (%)	JP-96 X RG-1771	1.76*	0.49	-0.50	H×L	3.15	47.70	-
	DPC-18 X RG-72	1.75	-0.06	0.61	L×H	4.32*	48.25	DMPS
	M-574 X RG-2661-1	1.42*	-1.03	0.26	L×H	0.75	46.59	-

Table 6 Three crosses based on *per se* performance for yield and yield traits in castor

Traits	Crosses	*Per se*	SCA effect	GCA status	Standard heterosis
	DPC-18 X G-3160	98.50	-1.688	H × L	11.93 **
Days to maturity of primary spike	DPC-9 X RG-43	98.00	4.338 **	H × L	11.36 **
	VP-1 X RG-72	97.00	4.175 **	H × L	10.23 **
	M-574 X RG-3160	15.00	0.275	H × H	13.94 **
Number of nodes up to primary spike	M-574 X RG-2661-1	14.72	0.304	H × H	11.77 *
	VP-1 X RG-2661-1	14.66	1.156 *	L × H	11.39 *
	VP-1 X RG-3160	40.83	3.472	H × H	178.45 **
Effective length of primary spike (cm)	VP-1 X RG-1608	39.17	3.939	H × L	167.10 **
	JP-96 X RG-109	38.83	3.369	H × H	164.81 **
	DPC-9 X RG-3160	58.33	5.995	H × H	230.23 **
Number of capsules on primary spike	DPC-9 X RG-392	57.81	6.986	H × H	227.29 **
	VP-1 X RG-2661-1	56.72	6.254	H × H	221.06 **
	DPC-9 X RG-2661-1	8.84	2.756 **	H × H	308.08 **
Number of effective spikes per plant	DPC-9 X RG-109	8.28	2.313 **	H × H	282.45 **
	VP-1 X RG-3160	7.90	2.112 **	H × L	264.90 **
	DPC-9 X RG-109	39.44	3.608 *	H × H	35.35 **
100-seed weight (g)	DPC-18 X RG-392	36.78	3.054	H × H	26.22 **
	DPC-9 X RG-2661-1	36.59	1.689	H × L	25.55 **
	VP-1 X RG-3160	68.07	2.200	H × H	24.04 *
Volume weight (g)	JP-96 X RG-3160	67.78	3.530	H × H	23.51 *
	JP-96 X RG-43	66.27	0.665	H × H	20.76 *
	VP-1X RG-109	105.04	32.935 **	H × H	260.05 **
Seed yield per plant (g)	DPC-18 X RG-1771	98.26	34.060 **	H × L	236.80 **
	DPC-18 X RG-2661-1	97.97	19.097	H × H	235.80 **
	DPC-18 X RG-72	48.25	1.758	L × H	4.32 *
Oil content (%)	JP-96 X RG-1771	47.70	1.763 *	H × L	3.15
	DPC-9 X RG-392	47.60	1.240	H × L	2.93

In this study, the parents JP-96, VP-1, DPC-9, RG-2661-1, RG-109 and RG-3160 were identified as good general combiners for seed yield and its components. The hybrid, DPC-18 × RG-2661-1 was identified as good specific combiner for early flowering and maturity, which has the advantage in the rainfed situations to escape the terminal moisture stress.

The hybrid combinations: VP-1 × RG-109 (105.04 g/plant), DPC-18 × RG-1771 (98.26g/plant) and DPC-18 × RG-2661-1 (97.97 g/plant) recorded higher seed yield. These three crosses showing high mean and significantly positive SCA effects for seed yield involved high × high and high × low GCA effects of parents. Hence, these cross combinations are promising in breeding programme for improvement of yield in castor.

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