Received: 12 Jul 2023 | Revised: 20 Sep 2023 | Accepted: 20 Sep 2023

Electronic Journal of Plant Breeding

Research Article

Genetic dissection of heterosis and combining ability in castor (*Ricinus communis*. L)

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Abstract
The estimates of combining ability and nature of gene action were worked out by Line x Tester analysis (Kempthorne, 1957). The experimental material included 45 entries containing six pistillate lines (DPC 9, DPC 21, D PC 24, YRCP 1, YRCP 2 and JP 65), five monoecious lines (TMV 5, SKI 215, 48-1, M3/28-3-1, and JM 6), thirty cross combinations, and four standard checks (YRCH 1, YRCH 2, ICH 66, and YTP 1). Four hybrids (DPC 9 x M3/28-3-1, DPC 9 x TMV 5, JP 65 x M3/28-3-1 and JP 65 x 48-1) exhibited high and significant positive economic heterosis for seed yield. The combining ability analysis demonstrated that the mean sum of squares due to genotypes and crosses were significant for all yield and its contributing traits. The magnitude of genetic variances for 11 quantitative traits revealed the predominance of dominant gene action for all the traits except oil content and hundred seed weight. For most traits, testers contributed more to total variance than the lines and L x T interaction. DPC 9, DPC 24, TMV 5, and JP 65 were identified to be the best general combiners for seed yield and its yield components. The hybrids DPC 9 x M3/28-3-1, DPC 9 x TMV 5, JP 65 x M3/28-3-1, and JP 65 x 48-1 were the most effective specific combiners for seed yield and also exhibited significant and high standard heterosis in the desired direction for seed yield and majority of the yield contributing traits. Hence, these parents and cross combinations could be effectively utilized for development of high yielding castor hybrids.

Keywords: Heterosis, Gene action, Combining ability, Seed yield

INTRODUCTION

Castor is an important industrial non-edible oilseed crop. It is most widely distributed in tropical, subtropical and mild temperate regions of the world and usually found in waste land, roadside and nearby households in rural and urban areas (Memon *et al*. 2023). Castor (*Ricinus communis* L., 2n=2x=20) belongs to Ricinae tribe of spurge family Euphorbiaceae. It is said to have a polyphyletic origin; both India and Africa were thought to be the places of origin of castor based on its extensive cultivation, documentation of its therapeutic usage, and physical evidence (Milani & Nobrega, 2013). It can be grown as annual in temperate regions and perennial in tropical and subtropical regions (Chakrabarthy *et al*. 2021) Castor is a versatile crop for commercial usage due to the presence of unique fatty acid Ricinoleic acid (80-90%) and high oil content (45-55%) in the seed (Lavanya *et al*. 2018). The castor seed oil is used as a raw material for a wide range of industrial products including high quality aircraft lubricants, coatings, paints, cosmetics, waxes, soaps, medications, perfumes, surfactants, resins, additives in petroleum diesel etc. (Singh *et al*. 2015). India is the leading producer of castor and achieved monopoly in castor cultivation with the production of 1.96 million tonnes and productivity of 1937 kg/ha from an area of 6.27 lakh hectares (Muralidharan, 2023). It is a cross-pollinated crop with 5-50% natural outcrossing which could reach 90–100% but in some dwarf cultivars. Heterosis breeding is significant for the development of superior hybrids in cross pollinated crops like castor. The goal of heterosis breeding is to determine the ideal cross combination that produces a high degree of useful heterosis and to characterise hybrids for commercial exploitation (Chaudhari and Patel, 2014). The majority of the castor crop area is covered by hybrids. The existence of heterosis for seed yield and yield components results in a higher hybrid seed production thus, estimating heterosis is crucial for hybrid development in castor (Singh *et al*. 2013). The commercialization of hybrid vigour in castor has become practical and cost-effective due to the availability of 100% pistillate lines that enable large-scale hybrid seed production. Improving the yield potential of this crop requires identifying superior parental combinations that can produce the appropriate level of heterotic impact. To tap the heterotic component of castor, it is crucial to select the best pistillate and monoecious lines and their best cross-combinations.

For development of better hybrids, selection of superior parents based on combining ability is one of the important steps. Increasing the yield of this significant oilseed crop necessitates knowledge of the nature of gene action involved in the expression of quantitative traits of economic significance, as well as the nature of combining abilities among a vast array of genetic materials to be used as parents in the hybridization programme (Priya *et al*. 2018). As a result, the current study was done to identify the best combiners with high degree of heterosis and to identify the most heterotic hybrids in castor.

MATERIALS AND METHODS

The present study was carried out during rabi season of 2022-23 at Tapioca and Castor Research Station, Yethapur (11º 35' N latitude, 78º 29' E longitudes and altitude 282 m) Salem district, Tamil Nadu. Six elite pistillate lines were crossed with five diverse monoecious line (**Table 1**) in Line x Tester fashion. The thirty hybrids thus generated were raised along four checks (YRCH-1, YRCH-2, ICH-66 and YTP-1) in a randomized block design, replicated twice. The recommended package of practices were followed for better crop establishment and growth. Observations were recorded on 11 yield and its contributing traits *viz*., Days to 50% flowering, Days to maturity of primary raceme, Plant height(cm), Number of nodes upto primary spike, Number of effective spikes per plant, Effective primary spike length (cm), Effective secondary spike length (cm), Effective tertiary spike length (cm), Hundred seed weight (g), Oil content (%) and Seed yield (kg/ha), in 10 randomly selected plants in each entry. Data recorded were subjected to analysis of variance for experimental design according to Panse and Sukhatme (1978) to find out the significant differences among genotypes. They were computed according to the line x tester method given by (Kempthorne, 1957) using TNAUSTAT (Manivannan N, 2014) software. Estimation of heterosis: The mean values of the biometrical traits of 30 hybrids and standard check hybrids were used to estimate the heterosis. The standard heterosis was estimated by following formulae suggested by Falconer, 1994. The significance of standard heterosis estimates was computed at error degrees of freedom as suggested by Turner (1953).

Table 1. The list of the castor genotypes used in the study and their characteristics

Genotype	Parentage	Source	Characteristics
		Testers	
TMV 5	SA2/S248-2, Inbred line	Oilseeds research station, Tindivanam	Resistant to leafhopper, medium duration variety
SKI 215	(SKI 8A X SA2) F_{10}	Main Castor &Mustard Research Station, S.K.Nagar, Gujarat	Non spiny, double bloom monoecious line
48-1	High oil mutant x Mauthner's dwarf	DOR, Hyderabad.	Resistant to Fusarium wilt and tolerant toBotrytis, Tolerant to saline and droughtconditions
M3/28-3-1	Mutant	TCRS, Yethapur	Triple bloom, spiny monoecious line
JM 6	-	Main Oilseeds Research Station, JunagadhAgricultural University, Junagadh.	Late duration variety, monoecious line
		Lines	
DPC 9	VP-1 X 128-1	IIOR, Hyderabad	Early maturing, short stature S type pistillate line
DPC 21	-	IIOR, Hyderabad	Improved pistillate line with good combining ability, earliness
DPC 24	-	IIOR, Hyderabad	Double bloom, spiny, pistillate line
YRCP 1	Spontaneous mutant of TMV 5	TCRS, Yethapur	Pistillate line, triple bloom
YRCP 2	-	TCRS, Yethapur	Pistillate line, triple bloom
JP 65	-	Main Oilseeds Research Station, JunagadhAgricultural University, Junagadh.	Zero bloom, spiny, pistillate line

Combining ability analysis: Combining ability refers to the ability of parents to combine well with each other during hybridization such that desirable traits get transferred to the progenies. Further combining ability was classified into general combining ability and specific combining ability. GCA refers to the average performance of the inbred line in all cross combinations whereas SCA refers to value of an inbred line in a specific cross. The general combining ability effects of parents and specific combining ability effects of hybrids were estimated by line x tester analysis (Kempthorne, 1957) using TNAUSTAT (Manivannan N, 2014) software.

RESULTS AND DISCUSSION

Analysis of variance for experimental design: Results of ANOVA showed that the mean sum of squares due to genotypes and hybrids were significant for all the 11 quantitative traits whereas mean squares due to L x T interaction were significant for all except primary spike length, secondary spike length, hundred seed weight and oil content. This indicates that there is considerable variation among the parents and hybrids for all the trait. The mean squares due to check *vs* hybrids showed non-significance for the traits, number of nodes upto primary spike, effective length of primary spike, effective length of tertiary spike and oil content. The significant mean squares due to genotypes indicated the existence of genotypic variation among the genotypes, which could be exploited for the improvement of respective traits. Anjani (2010) revealed significant genotypic variation for the majority of the traits he investigated, indicating that efficient selection might be conceivable.

ANOVA for combining ability: Based on the ANOVA for combining abilities (**Table 2**), it was obvious that there were significant differences detected for all attributes except for effective length of secondary spike in lines. In testers, the characters, effective length of the tertiary spike, and oil content were non-significant, whereas others were highly significant.

The genetic variances and its magnitude for 11 seed yield and its contributing traits were assessed and listed in the **Table 3**. For all traits, with the exception of oil content and hundred seed weight, the SCA variance were found to be greater than the GCA variances, indicating the predominance of non-additive gene action. These are in accordance with the findings of Punewar *et al*. (2017), Chaudhari and Patel, (2014), Kavani *et al*. (2016), Priya *et al*. (2018), Mohanty *et al*. (2021), Sapovadiya *et al.* (2015), Dube *et al*. (2018). The GCA variance were greater than the SCA variance for oil content and hundred seed weight. This indicates that those two traits were controlled by additive gene action. As observed in the present study, the predominance role of additive gene action was also observed by Ramesh *et al*. (2013), Salihu *et al*. (2018), Priya *et al*. (2018), Patel *et al*. (2017) for hundred seed weight and oil content. The ratio of additive (σ^2_A) to dominance (σ^2_D)variances revealed that among the 11 biometrical traits, hundred seed weight (1.02) and oil content (1.10) showed the preponderance of additive gene action. The GCA variance ranged from -2394.88 (Seed yield) to 16.28 (Plant height) while, SCA variance ranged from 0.1145 (Oil content) to 563339.56 (Seed yield).

Contribution of testers, lines and L x T interaction to the total variance: The **Table 4.** illustrated the proportional contribution of lines, testers, and the 'L x T' interaction to yield and its attributing features. Lines imparted the greatest contribution to yield and its related attributes, followed by the 'L x T' interaction for the traits, days to 50% flowering, days to maturity, plant height, effective length of primary spike, effective length of secondary spike, hundred seed weight, and oil content. For the traits, number of nodes up to major spike and Seed yield, the contribution of testers was found to be greater than that of both lines and the 'L x T' interaction. As a result, the lines and 'L x T' interaction contributed more to the total variance for almost all the traits.

Table 2. Analysis of variance for combining ability

SOURCE OF VARIATION	df	MEAN SQUARES										
		DFF	DM	PH	NUP	ESP	PSL	SSL	TSL	HSW	OC	YLD
REPLICATION	1	0.02	0.02	99.84	3.65	3.26	298.37	95.76	0.01	3.31	0.46	8693.11
CROSSES	29	149.74**	149.74**	824.85**	18.84**	75.66**	115.62**	53.38**	15.93**	30.61**	3.29**	1057538.59**
LINE	5	335.89**	335.89**	2162.86**	43.65**	57.86**	369.05**	143.75	20.73**	104.60**	12.65**	1271442.42**
TESTER	4	247.72**	247.72**	1628.67**	59.62**	33.71**	87.45**	65.59**	7.89	55.66**	1.20	425971.45**
LXT INTERACTION	20	83.60**	83.60**	329.58**	4.48**	88.51**	57.90**	28.34**	16.34**	7.11	1.37	1130376.07**
ERROR	29	0.70	0.70	68.59	2.05	2.57	29.32	24.50	5.82	4.07	1.14	3696.95

NOTE: ** - Significant at 5%, * - Significant at 1%

Where, DFF- Days to 50% flowering, DM- Days to maturity, PH- Plant height(cm), NUP- Number of nodes upto primary spike, ESP- Number of effective spikes per plant, PSL- Effective length of Primary spike (cm), SSL- Effective length of Secondary spike (cm), TSL- Effective length of Tertiary spike (cm), HSW- Hundred seed weight(g), OC- Oil content (%) and yld - Seed yield (kg/ha).

Table 3. Magnitude of genetic variances for eleven quantitative traits of castor

CHARACTERS	σ^2GCA	σ^2SCA	σ^2A	σ^2D	σ^2GCA/σ^2SCA	σ^2A/σ^2D
Days to 50% flowering	2.17	41.45	4.35	41.45	0.05	0.10
Days to maturity	2.17	41.45	4.35	41.45	0.05	0.05
Plant Height	16.28	130.50	32.57	130.50	0.12	0.25
No of nodes upto primary spike	0.47	1.22	0.94	1.22	0.39	0.78
No of effective spikes per plant	-0.42	42.97	-0.84	42.97	-0.01	-0.02
Effective length of primary spike	1.89	14.29	3.80	14.29	0.13	0.27
Effective length of secondary spike	0.82	1.92	1.65	1.92	0.43	0.86
Effective length of tertiary spike	-0.01	5.26	-0.03	5.26	-0.002	-0.01
Hundred Seed Weight	0.77	1.52	1.55	1.52	0.51	1.01
Oil Content	0.0632	0.1145	0.1264	0.1145	0.55	1.10
Seed Yield	-2394.88	563339.56	-4789.77	563339.56	-0.004	-0.001

Table 4. Proportion of contribution of lines,testers and line x tester for yield and its attributing traits in castor

SOURCE	DFF	DM	PH	NUP	ESP	PSL	SSL	TSL	HSW	OC	YLD
LINES	38.68	38.68	45.21	39.94	13.18	55.03	46.43	22.43	58.90	66.18	20.73
TESTERS	22.82	22.82	27.23	43.64	6.15	10.43	16.95	6.83	25.07	5.04	5.56
L X T INTERACTION	38.51	38.51	27.56	16.42	80.67	34.54	36.62	70.73	16.02	28.77	73.72

General combining ability effects of Parents: Seed yield is the prime objective for castor breeders. Among the lines, DPC 9 (534.28), JP 65 (163.96) and DPC 24 (152.55) exhibited positive significant *gca* effects for seed yield whereas in testers, M3/28-3-1 (213.46) and TMV 5 (153.65) showed significant positive GCA (**Table 5**). Thus, the female parents DPC 9, JP 65, DPC 24 and male parents TMV 5, M3/28-3-1 can be used to achieve higher yields through hybridization programme. The lines DPC 9 (-10.48), DPC 24 (-1.08) and testers TMV 5 (-5.82), SKI 215 (-1.07) showed negative significant GCA for days to fifty percent flowering. Earliness in castor was the most desirable trait and the above parents were found to be best combiners for days to 50% flowering. The lines DPC 9, DPC 21 and tester TMV 5 were the best general combiners for plant height and number of nodes upto primary raceme as they showed significant negative *gca* effects. Hence, dwarf stature and minimal number of nodes upto primary spike can be achieved by combining these above parents. The female parents, DPC 24 (5.36) and JP 65 (8.66) revealed significant positive *gca* effects for effective length of primary spike while all the male parents exhibited non-significant for this trait. JP 65 (5.02) and DPC 9(4.02) from lines and TMV 5 (3.76) from testers exhibited positive significant *gca* effects for effective length of the secondary spike. Among all the lines and testers, the line JP 65 (2.44) alone showed significant positive *gca* effects for effective length of the tertiary spike. The line, DPC 9 (1.72) has been identified as the best general combiner for oil content. The pistillate lines, JP 65 (4.57) and DPC 9 (1.73) and monoecious line JM 6 (3.14) registered significant positive *gca* effects for hundred seed weight.

Among all the pistillate lines, DPC 9 was found to be best combiner for all the traits followed by JP 65 which was the best combiner for five traits *viz*., effective length of primary spike, effective length of secondary spike, effective length of tertiary spike, hundred seed weight and seed yield). The tester TMV 5 was found to be the best combiner for most of the traits. Thus, Crosses involving these parents would result in the production of superior segregants with desirable genes for early maturation, long spikes coupled with high yield.

Specific combining ability effects of hybrids: Out of the 30 cross combinations studied, 16 hybrids showed significant positive *sca* effects for seed yield (**Table 6**). The cross combination DPC 9 x M3/28-3-1 (1561.59) exhibited highest significant positive *sca* effects for seed yield, followed by the crosses, DPC 9 x TMV 5 (1192.19), DPC 9 x JM 6 (1088.27), JP 65 x 48-1 (706.64), YRCP 2 x JM 6 (595.06) and JP 65 x M3/28-3-1 (508.11). For the traits, days to fifty percent flowering and days to maturity of primary spike, the cross combination DPC 21 x SKI 215 (-11.23) showed the highest significant negative *sca* effects, thus it helps in achieving the development of early maturing hybrids in castor. The high and significant negative *sca* effects for plant height was exhibited by the cross combination, DPC 21 x SKI 215 (-18.92) followed by YRCP 2 x JM 6 (-16.73). For number of effective spikes per plant, the cross YRCP 1 x TMV 5 (19.73)

Table 5. Estimates of general combining abilities(*gca*) effects of parents for yield and yield components

PARENTS	DFF	DM	PH	NUP	ESP	PSL	SSL	TSL	HSW	OC	YLD
						LINES					
DPC 9	-10.48**	-10.48**	-11.56**	-2.37**	2.82**	-0.88	4.02*	-1.60*	1.73*	1.72**	534.28**
DPC 21	1.82**	1.82**	-16.28**	-2.53**	-2.24**	-7.86**	-2.86	-1.00	-5.09**	0.40	-463.37**
DPC 24	-1.08**	-1.08**	19.14**	2.07**	-1.04*	5.36**	0.32	0.56	-0.31	-1.29**	152.55**
YRCP 1	-0.18	-0.18	16.76**	2.09**	2.92**	-1.20	-2.56	-0.68	0.56	-0.44	-121.78**
YRCP 2	3.52**	3.52**	-2.84	-0.31	0.06	-4.10*	-3.96*	0.28	-1.45*	0.61	-265.65**
JP 65	6.42**	6.42**	-5.24	1.03*	-2.52**	8.66**	5.02**	2.44**	4.57**	-0.99**	163.96**
						TESTERS					
TMV 5	-5.82**	-5.82**	-16.82**	-3.26**	2.03**	-1.53	3.76*	-0.52	-2.76**	-0.23	153.65**
SKI 215	-1.07**	-1.07**	1.38	-0.46	-1.05*	-1.25	-2.28	-1.09	0.40	0.31	-245.70**
48 - 1	0.60*	0.60*	-3.78	-0.16	1.30**	-2.96	-1.48	0.13	0.18	0.31	-10.32
M3/28-3-1	-0.57*	-0.57*	4.17	1.10*	-0.20	2.87	0.44	0.55	-0.97	-0.40	213.46**
JM 6	6.85**	6.85**	15.05**	2.79**	-2.07**	2.87	-0.44	0.93	3.14**	0.02	-111.09**
CD(P=05)	1.63	1.63	17.21	2.74	3.86	11.66	10.15	4.89	4.11	2.23	119.46
CD(P=01)	2.17	2.18	22.95	3.66	5.15	15.55	13.53	6.51	5.47	2.98	159.28

NOTE: * - Significant at 5%,   ** - Significant at 1%

depicted highest significant positive *sca* effect followed by the cross JP 65 x JM 6 (6.27). The hybrid, DPC 21 x M3/28-3-1 (3.93) recorded positive significant *sca* effect for the effective length of tertiary spike. For hundred seed weight, only one cross YRCP1 x TMV 5 (3.34) exhibited significant positive *sca* effect. Among all, the hybrids, DPC 9 x SKI 215 (days to 50% flowering, days to maturity, plant height, number of effective spikes per plant), DPC 24 x 48-1 (days to 50% flowering, days to maturity, plant height, seed yield), YRCP 1 X TMV 5 (plant height, number of effective spikes per plant, hundred seed weight, seed yield), YRCP 2 X JM 6 (days to 50% flowering, days to maturity, plant height, seed yield), and JP 65 X JM 6 (days to 50% flowering, days to maturity, number of effective spikes per plant, seed yield) recorded significant *sca* effects for four traits. No crosses recorded significant *sca* effects for the traits such as effective length of primary spike, effective length of secondary spike, number of nodes upto primary spike and oil content. Among 30 hybrids, DPC 9 x TMV 5 and DPC 9 x M3/28-3-1 were the best specific combiners for early maturing and higher seed yield. According to the preceding explanation, the gene action governing the qualities under study was non-additive and non-fixable for the majority of the traits. As a result, selection for improving these characteristics may be deferred to a subsequent generation.

Magnitude of heterosis: In the present study, standard heterosis of the hybrids over the best standard check hybrid (YRCH 1) was estimated for 11 yield and yield attributing traits and presented in the **Table 7.** The range of standard heterosis varied from -56.86 (DPC 21 x M3/28-3-1) to 130.57 (DPC 9 x M3/28-3-1) for seed yield. The highest magnitude of standard heterosis for seed yield was exhibited by the cross DPC 9 x M3/28-3-1 (130.57). Out of 30 hybrids developed, nine cross combinations (DPC 9 x TMV 5, DPC 9 x M3/28-3-1, DPC 24 x SKI 215, DPC 24 x 48-1, DPC 24 x M3/28-3-1, YRCP 1 x TMV 5, YRCP 2 x JM 6, JP 65 x 48-1 and JP 65 x M3/28-3-1) exhibited significant and positive standard heterosis for seed yield. Early flowering and early maturity is most desirable trait for castor improvement. In the present study, the hybrids, DPC 9 x TMV 5 (-17.28), DPC 9 x SKI 215 (-6.17) and DPC 9 x M3/28-3-1 (-9.88) revealed significant and negative standard heterosis for the days to 50% flowering and days to maturity of primary spike. Significant negative useful heterosis for days to 50% flowering and days to maturity in castor were reported by Delvadiya *et al.* (2018), Patel *et al.* (2015). For plant height, the significant negative heterosis was observed in 11 cross combinations *viz*., DPC 9 x TMV 5 (-32.21), DPC 9 x SKI 215 (-27.37), DPC 9 x 48-1 (-26.95), DPC 21 x TMV 5 (-21.05), DPC 21 x SKI 215 (-38.74), DPC 21 x 48-1 (-17.26), DPC 21 x M3/28-3-1 (-18.63), DPC 21 x JM 6 (-5.68), DPC 24 x TMV 5 (-14.74), YRCP 1 x TMV 5 (-19.79) and YRCP 2 x TMV 5 (-21.58). Significant positive standard heterosis for number of effective spikes per plant was exhibited by DPC 9 x 48-1 (18.82) and YRCP 1 x TMV 5 (106.00) whereas, for effective length of primary spike, the positive and significant standard heterosis was observed in DPC 24 x M3/28-3-1 (41.08), JP 65 x M3/28-3-1 (42.16) and JP 65 x JM 6 (49.19). The hybrid JP 65 x TMV 5 (32.98) alone showed significant standard heterosis in desirable direction for effective length of secondary spike. Six crosses *viz*., DPC 21 x M3/28-3-1 (26.54), DPC 24 x 48-1 (26.54), YRCP 1 x JM 6 (34.05), JP 65 x TMV 5 (32.98), JP 65 x 48-1 (30.83) and JP 65 x JM 6 (34.58) depicted the significant positive

Table 6. Estimates of specific combining ability effects of hybrids among of eleven quantitative traits in castor

HYBRIDS	DFF	DM	PH	NUP	ESP	PSL	SSL	TSL	HSW	OC	YLD
DPC 9 X TMV 5	-1.68**	-1.68**	0.76	-1.12	-7.87**	3.61	0.54	-0.80	-1.14	0.12	1192.19**
DPC 9 X SKI 215	-1.93**	-1.93**	-12.84*	0.28	3.51**	5.63	-3.62	-0.33	2.10	-0.75	-472.80**
DPC 9 X 48-1	-1.60*	-1.60*	-7.28	-0.22	4.16**	-7.56	6.98	2.35	2.41	0.39	-1192.72**
DPC 9 XM3/28-3-1	-3.93**	-3.93**	10.67	-0.58	0.56	5.41	-0.44	-0.67	-1.59	0.03	1561.59**
DPC 9 X JM 6	9.15**	9.15**	8.69	1.63	-0.37	-7.09	-3.46	-0.55	-1.78	0.22	1088.27**
DPC 21 X TMV 5	-1.48*	-1.48*	16.08*	2.54*	-0.21	5.89	-4.08	-0.60	1.19	0.81	85.39
DPC 21 X SKI 215	-11.23**	-11.23**	-18.92**	-0.96	-1.43	0.41	2.46	-0.63	-0.77	0.18	21.53
DPC 21 X 48-1	5.60**	5.60**	6.64	0.94	0.62	-0.98	-1.04	-1.75	1.55	-0.37	367.92**
DPC 21 X M3/28-3-1	7.77**	7.77**	-2.61	-1.02	0.12	-6.61	3.14	3.93*	-2.06	-1.30	-635.78**
DPC 21 X JM 6	-0.65	-0.65	-1.19	-1.51	0.89	1.29	-0.48	-0.95	0.09	0.68	160.94**
DPC 24 X TMV 5	2.92**	2.92**	-13.34*	-1.46	-1.71	-2.03	-4.16	-4.56*	-0.04	0.38	-335.42**
DPC 24 X SKI 215	6.17**	6.17**	12.16*	1.24	-4.93**	-2.41	2.68	2.41	-0.15	0.23	351.88**
DPC 24 X 48-1	-4.00**	-4.00**	-15.08*	-0.76	0.72	0.60	-0.22	2.79	-1.08	0.10	139.30**
DPC 24 X M3/28-3-1	0.17	0.17	14.47*	1.68	0.32	5.47	-0.44	1.37	0.17	-1.07	-64.38
DPC 24 X JM 6	-5.25**	-5.25**	1.79	-0.71	5.59**	-1.63	2.14	-2.01	1.11	0.37	-91.38*
YRCP 1 X TMV 5	-0.48	-0.48	-15.76*	-0.58	19.73**	2.23	3.52	1.88	3.34*	-1.84*	347.21**
YRCP 1 X SKI 215	2.77**	2.77**	1.04	-1.28	0.41	4.95	-2.84	-0.45	-1.57	0.16	163.86**
YRCP 1 X 48-1	-0.40	-0.40	15.70*	-0.48	-4.24**	1.26	-3.04	-3.07	-3.26*	0.19	-193.77**
YRCP 1 X M3/28-3-1	-6.73**	-6.73**	-8.35	1.36	-8.74**	-9.37*	-3.36	-2.99	0.89	1.09	-632.35**
YRCP 1 X JM 6	4.85**	4.85**	7.37	0.97	-7.17**	0.93	5.72	4.63*	0.60	0.40	315.05**
YRCP 2 X TMV 5	-3.68**	-3.68**	2.14	-0.78	-5.31**	-3.87	-1.98	1.32	-2.76	0.44	-508.58**
YRCP 2 X SKI 215	-3.93**	-3.93**	18.24**	2.32*	0.87	-2.85	0.56	1.29	0.28	0.28	478.08**
YRCP 2 X 48-1	5.40**	5.40**	2.10	-0.58	1.52	2.86	-1.24	-2.03	1.69	0.30	172.64**
YRCP 2 X M3/28-3-1	9.07**	9.07**	-5.75	0.16	8.12**	2.53	3.14	2.15	1.60	0.37	-737.21**
YRCP 2 X JM 6	-6.85**	-6.85**	-16.73**	-1.13	-5.21**	1.33	-0.48	-2.73	-0.80	-1.39	595.06**
JP 65 X TMV 5	4.42**	4.42**	10.14	1.38	-4.63**	-5.83	6.14	2.76	-0.57	0.10	-780.79**
JP 65 X SKI 215	8.17**	8.17**	0.34	-1.62	1.55	-5.71	0.78	-2.27	0.12	-0.10	-542.56**
JP 65 X 48-1	-5.00**	-5.00**	-2.10	1.08	-2.80*	3.80	-1.42	1.71	-1.32	-0.61	706.64**
JP 65 X M3/28-3-1	-6.33**	-6.33**	-8.45	-1.58	-0.40	2.57	-2.04	-3.81*	0.99	0.88	508.11**
JP 65 X JM 6	-1.25*	-1.25*	0.07	0.73	6.27**	5.17	-3.46	1.61	0.78	-0.28	108.60*
CD(P=05)	1.63	1.63	17.21	2.74	3.86	11.66	10.15	4.89	4.11	2.23	119.46
CD(P=01)	2.18	2.18	22.95	3.66	5.15	15.55	13.53	6.51	5.47	2.98	159.28

NOTE: * - Significant at 5%, ** - Significant at 1%

useful heterosis for effective length of tertiary spike. Hundred seed weight is an important yield attributing trait which had the extent of standard heterosis in the desirable direction which ranged from -23.77 (DPC 21 x M3/ 28-3-1) to 30.66 (JP 65 x JM 6). Among all, eight cross combinations [DPC 9 x SKI 215 (16.72), DPC 9 x 48-1 (17.05), DPC 24 x JM 6 (15.74), YRCP 1 x JM 6 (16.89), JP 65 x SKI 215 (19.51), JP 65 x 48-1 (14.10), JP 65 x M3/28-3-1 (17.87) and JP 65 x JM 6 (30.66)] exhibited the significant positive heterosis over standard check hybrid (YRCH 1) for hundred seed weight. The best two hybrids which exhibited significant superior performance over standard check hybrid for oil content were DPC 9 x 48-1 (5.58) and DPC 9 x JM 6 (4.65).

From the present study, it can be concluded that among 30 hybrids, four hybrids DPC 9 x M3/28-3-1, DPC 9 x TMV 5, JP 65 x M3/28-3-1 and JP 65 x 48-1 recorded significantly highest positive standard heterosis, significant *sca* effects and corresponding parents also showed significant *gca* effects for seed yield. Thus, these above crosses could be effectively utilized for heterosis breeding to develop hybrids with higher seed yield. Among 11 parents, four parents *viz*., DPC 9, JP 65, TMV 5 and DPC 24 which had a high *gca* effects for yield and other important traits. It could be used to exploited in further breeding programme for developing superior segregants for early maturity, long spikes and higher seed yield.

Table 7. Magnitude of standard heterosis (%) for various characters in castor

HYBRIDS	DFF	DM	PH	NUP	ESP	PSL	SSL	TSL	HSW	OC	YLD
DPC 9 X TMV 5	-17.28**	-8.19**	-32.21**	-13.60	-41.94**	7.30	15.01	-7.77	-4.26	3.94	105.39**
DPC 9 X SKI 215	-6.17**	-2.92**	-27.37**	20.00	2.69	13.51	-19.39	-8.31	16.72*	3.26	-15.71**
DPC 9 X 48-1	-1.23	-0.58	-26.95**	18.40	18.82*	-26.76	19.06	12.60	17.05*	5.58*	-44.14**
DPC 9 XM3/28-3-1	-9.88**	-4.68**	0.32	25.60*	-8.60	24.05	0.51	-1.34	0.16	3.42	130.57**
DPC 9 X JM 6	40.74**	19.30**	9.68	56.80**	-23.66**	-9.73	-12.65	1.34	12.95	4.65*	-43.92**
DPC 21 X TMV 5	13.58**	6.43**	-21.05*	14.40	-27.96**	-5.41	-23.78	-3.49	-19.02**	2.67	-18.06**
DPC 21 X SKI 215	1.23	0.58	-38.74**	8.80	-51.08**	-19.46	-22.09	-6.70	-15.08*	2.47	-45.24**
DPC 21 X 48-1	46.91**	22.22**	-17.26	26.40*	-27.42**	-27.84	-31.20	-6.17	-8.20	1.35	-11.11**
DPC 21 X M3/28-3-1	49.38**	23.39**	-18.63*	20.80	-38.17**	-27.30	-10.62	26.54*	-23.77**	-2.00	-56.86**
DPC 21 X JM 6	46.91**	22.22**	-5.68	30.40**	-44.09**	-5.95	-25.80	2.41	-3.28	2.92	-29.16**
DPC 24 X TMV 5	17.28**	8.19**	-14.74	19.20	-29.57**	8.92	-13.32	-16.35	-7.38	-1.69	-6.62
DPC 24 X SKI 215	37.04**	17.54**	31.26**	63.20**	-63.44**	8.65	-10.62	17.96	2.62	-0.89	10.27**
DPC 24 X 48-1	16.05**	7.60**	-2.84	49.60**	-20.43*	12.16	-17.71	26.54*	-1.15	-1.16	11.61**
DPC 24 X M3/28-3-1	23.46**	11.11**	36.63**	79.20**	-30.65**	41.08*	-11.97	21.18	-0.82	-5.00*	12.78**
DPC 24 X JM 6	28.40**	13.45**	34.32**	73.60**	-12.37	21.89	-6.24	5.09	15.74*	-1.20	-7.83*
YRCP 1 X TMV 5	11.11**	5.26**	-19.79*	26.40*	106.99**	2.70	2.87	11.53	6.56	-4.49	17.33**
YRCP 1 X SKI 215	30.86**	14.62**	17.05	43.20**	-13.44	10.81	-38.95*	-4.02	0.82	0.71	-16.85**
YRCP 1 X 48-1	27.16**	12.87**	27.05**	52.00**	-25.81**	-3.78	-36.93*	-11.53	-5.41	0.78	-24.02**
YRCP 1 X M3/28-3-1	8.64**	4.09**	10.11	76.80**	-58.06**	-16.76	-31.53	-8.85	4.43	1.17	-36.63**
YRCP 1 X JM 6	55.56**	26.32**	38.11**	87.20**	-59.68**	11.08	-3.88	34.05*	16.89*	0.62	-0.09
YRCP 2 X TMV 5	12.35**	5.85**	-21.58*	5.60	-43.01**	-21.62	-20.40	13.67	-20.00**	2.33	-41.31**
YRCP 2 X SKI 215	23.46**	11.11**	14.53	52.80**	-26.34**	-18.11	-32.21	10.46	0.33	3.10	-6.85
YRCP 2 X 48-1	50.62**	23.98**	-7.89	32.00**	-10.22	-7.30	-35.58*	-0.80	4.26	3.13	-10.96**
YRCP 2 X M3/28-3-1	56.79**	26.90**	-7.79	48.00**	17.20	7.57	-14.33	23.86	0.16	1.84	-51.21**
YRCP 2 X JM 6	35.80**	16.96**	-7.89	51.20**	-64.52**	4.32	-29.51	-0.27	5.74	-0.91	7.90*
JP 65 X TMV 5	39.51**	18.71**	-15.68	33.60**	-53.23**	7.57	37.27*	32.98*	6.89	-1.65	-32.08**
JP 65 X SKI 215	60.49**	28.65**	-6.84	32.00**	-36.56**	8.65	-1.18	2.95	19.51**	-0.94	-41.53**
JP 65 X 48-1	32.10**	15.20**	-14.84	56.00**	-47.31**	29.73	-5.90	30.83*	14.10*	-1.98	45.56**
JP 65 X M3/28-3-1	25.93**	12.28**	-13.16	44.80**	-42.47**	42.16**	-1.52	3.49	17.87*	-0.39	47.04**
JP 65 X JM 6	56.79**	26.90**	7.26	76.80**	-16.67	49.19**	-9.27	34.58*	30.66**	-1.89	4.56

NOTE: * - Significant at 5%, ** - Significant at 1%

Where, DFF- Days to 50% flowering, DM- Days to maturity, PH- Plant height(cm), NUP- Number of nodes upto primary spike, ESP- Number of effective spikes per plant, PSL- Effective length of Primary spike (cm), SSL- Effective length of Secondary spike (cm), TSL- Effective length of Tertiary spike (cm), HSW- Hundred seed weight (g), OC- Oil content (%) and yld - Seed yield (kg/ha).

ACKNOWLEDGEMENT

We are extremely grateful to Tapioca and Castor Research Station, Yethapur, for providing facility for this research study.

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