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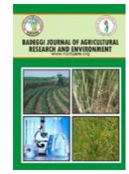

Research Article

Identification of Superior Donor Parents for Earliness and other Yield Components in Castor

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Abstract
Castor oil plant (*Ricinus communis* L.) is one of underutilized African oil crops with little research attention in Nigeria. In this research, six castor parents were evaluated for their combining ability using Griffins Method IV. The research was aimed at identifying superior donor parents for earliness and other yield component traits. Partial diallel crosses were made among the six parents to generate 15 F_1 hybrids. The parents and their hybrids were evaluated in a randomized complete block design for two growing seasons. The result showed significant differences for both general combining ability (GCA) and specific combining ability (SCA) for all the traits studied. Predominant non-additive gene variance was observed for seedling establishment, days to first spike flowering, height at flowering, branches per plant, spike length, capsules per plant, seed yield and seed oil content. Additive gene variance was higher for days to maturity, height at maturity, spikes per plant and seed weight. The broad sense heritability and narrow sense heritability ranged from 86.64 % to 99.90 % and 0.19 % to 67.78 % respectively for the traits studied. Significant desirable GCA effects for both earliness to flowering and earliness to maturity were observed in Parents 1 (P1). Parents P1, P4 and P5 recorded desirable effects for seed yield. P1 and P5 were found to be good overall combiners for all the traits evaluated. Three hybrids (P1×P2, P2×P5 and P3×P4) showed simultaneous significant SCA effects for both days to flowering and days to maturity. Eight hybrids were found to be good overall specific combiners for all the traits studied. These findings revealed the potentials of each of the parents in creating populations with high frequency of desirable genes for the traits studied. The parents showed high potentials and could be used in developing improved castor populations in Nigeria.

Keywords: Donor parents, Combining ability, Castor, Earliness, Yield components

Introduction

Castor oil plant (*Ricinus communis* L.) is one of neglected African crops with high economic values (Gana *et al.*, 2013). The crop has been demonstrating its economic potentials around the world, contributing notable foreign exchange credits to economy of many countries including India, Brazil and China (Ibeagha and Onwualu, 2015). Castor has been identified as an ideal crop which has potential to generate thousands of jobs for Nigerian youths and women (Adeleke *et al.*, 2009). The crop presently serves as an alternative source of income to Nigerian farmers across the country (Amosun *et al.*, 2013). Also, being a hardy and low nutrient demanding crop, it helps in reclaiming marginalized farm land (Gana *et al.*, 2013). The oil, which is extracted from castor seed, is very critical to many industrial applications because of its ability to form many important derivatives (Ogunniyi, 2006). The oil is used in the manufacturing of medicine, cosmetics, paints, dyes, inks, waxes/polishes, nylon, paper, textile and cold resistant plastic to hydraulic fluids and lubricants/biodiesel (Mutlu and Meier, 2010).

Despite the huge economic benefits, castor breeding in Nigeria has not been receiving much attention, resulting to lack of improved varieties with high seed yield, non-shattering capsules, early maturity and good architecture for

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mechanization among others (Gana, 2015). Breeding for superior castor genotypes have been achieved in many countries using various breeding methods (Shivanna, 2008). However, for any successful breeding programme, identification of appropriate parents is very crucial (Shivanna, 2008). Information on magnitude of combining ability for seed yield and its related characteristics are of high priority. Several authors have reported the importance of both general combining ability (GCA) and specific combining ability (SCA) in expression of agronomic traits in castor (Tank *et al.*, 2003; Solanki *et al*., 2004; Patel and Chauhan, 2013). Ramesh *et al.* (2013) reported ratio of GCA variance and SCA variance in favour of preponderance of non-additive gene action for all the traits except plant height to primary spike, number of nodes to primary spike, capsules per spike and total length of secondary spike. One parent was observed to be a good combiner for most of the characters studied (Ramesh *et al*., 2013). It was reported that the best performing hybrids with high mean seed yield and positive significant SCA effects for seed yield were generated from either high performing parent hybridized with average performing parent (High xAverage), high performing parent crossed with high performing parent (High × High), average performing parent crossed with average performing parent (Average × Average), or when average performing parents were crossed with high combiners for seed yield (Shivanna, 2008). Golakia *et al.* (2015) reported importance of GCA effects for days to flowering of primary spike and seed yield per plant, and superiority of SCA effects for days to primary spike maturity and nodes up to primary spike. Two good combiners were observed for earliness and seed yield per plant. Information on combining ability for seed yield and its related characteristics are of high priority in identifying appropriate breeding techniques to achieve a desired improvement. Such information also provides guidelines to the breeders in choosing the appropriate parents for precise improvement programme. Under these ideas, the present research was aimed at identifying superior donor genotypes for earliness and other yield component traits in castor through combining ability analysis.

Materials and Methods

The castor genetic materials used for this research were obtained from Castor Research Programme of National Cereals Research Institute (NCRI) Badeggi, Nigeria. Six (6) castor parents were used for the study. The parents include: (1) NCRICAS/Acc.005 – S5 – 2, a small seeded castor with high number of spikes per plant; (2) NCRICAS/Acc.010 – S4 – 5, a small seeded castor with high number of capsules per spike, long effective spike length and high seed oil content; (3) NCRICAS/Acc.036 – S5 – 8, a medium seeded castor with high number of spikes per plant; (4) NCRICAS/Acc.001 – S6 – 10, a white large seeded castor; (5) NCRICAS/Acc.036M – S4 – 20, a medium seeded castor with high number of spikes per plant and high seed oil content; (6) NCRICAS/Acc.045 – S5 – 4, a black large seeded castor with high number of fruit bearing branches.
Random seed samples from each of the parents were used to establish crossing block in January 2016, using irrigation facility at the Sugarcane Research Field of NCRI Badeggi, Nigeria. Two sets of blocks were established at different planting dates (15 days interval) to synchronize the flowering periods of the parents. The selected female flowers were covered with brown envelops prior to flower opening to control the pollination. Emasculation was effected prior to anthesis by the use of forceps. The pollens were collected in the evening (5 - 6 pm) and stored in white envelope for pollination in the next day. Pollination was effected 1 to 5 days after anthesis. Partial diallel crosses were made to generate 15 hybrids. After the artificial pollination, the pollination envelops were replaced and appropriate labeling were ensued. For the purpose of this research, the six parents were coded as:
P1 for NCRICAS/Acc.005–S5–2,
P2 - NCRICAS/Acc.010–S4–5,
P3 - NCRICAS/Acc.036–S5–8,
P4-NCRICAS/Acc.001–S6–10,
P5-NCRICAS/Acc.036M–S4–20, and
P6-NCRICAS/Acc.045–S5–4

The six castor parents and their 15 F_1 hybrids were evaluated for combining ability between June and December of 2016 and 2017 raining seasons. For each set of the crosses, 45 plant samples of F_1 and parents were evaluated. The entries were laid out on Randomized Complete Block Design with three replications. Standard agronomic practices for castor (Gana, 2015) were followed. Morphological data were taken according to Indian castor descriptor (India, 2004). General analysis of variance was carried out to test for significant of variability among the crosses. Combining ability analysis and variance component estimates were computed following the procedure of Plant Breeding Tools (PBTools, 1.3) for Griffing Diallel Method IV. Ranking for overall general and overall specific combining ability were carried out according to Shivanna (2008).

Results and Discussion

The results of general analysis of variance for the 12 traits evaluated among the crosses are presented in Table 1. Individual analysis of variance as well as combined analysis showed significant differences for all the studied traits among the crosses. No significant effect of year variation was recorded for the traits. Genotypes by year interaction was only significant for effective spike length among all the traits studied. The mean performances of the parents and their hybrids are showed in Table 2. The results revealed presence of sufficient genetic variability for the characters among the crosses and as such revealing appropriateness of the data for genetic analysis. The findings reported here are similar to the reports of Allan *et al.* (2008), Rao *et al.* (2009) and Zheng *et al.* (2010). Golakia *et al.* (2015) documented adequate genetic variability for the most of characters in castor, including seed yield per plant. Individual ANOVA for combining ability (GCA) showed significant difference for days to flowering, height at flowering, days to maturity, spikes per plant and seed weight in both first year (Year 1) and second year (year 2) of evaluation (Table 3). Significant specific combining ability (SCA) was recorded for all the traits at both years of evaluation (Table 3). The combined analysis of variance for combining ability showed significant differences for both general combining ability (GCA) and specific combining ability (SCA) for all the traits evaluated over the two years (Table 3). No genotype by year interaction was observed for both GCA × Y and SCA × Y in all the traits.

The significant differences of both general combining ability (GCA) and specific combining ability (SCA) for the traits observed is an indication of the importance of both additive gene effects and non-additive gene effects in the inheritance of the traits. Similar findings on the involvement of both effects due to additive and non-additive genes for all the traits in castor have been earlier reported by Ramesh *et al.* (2013). Golakia *et al.* (2015) reported importance of GCA effects (additive gene actions) for days to flowering of primary spike and seed yield per plant, and superiority of SCA effects (non-additive gene actions) for days to primary spike maturity and nodes up to primary spike.

Genetic variance due to additive gene actions and non-additive genes actions are presented in Table 4. The combined results showed predominance of non-additive gene variance for seedling establishment, days to flowering, height at flowering, branches per plant, effective spike length, capsules per plant, seed yield and seed oil content. This suggests inter-population improvement strategies for the improvement of these traits. Additive gene variance was higher for days to maturity, height at maturity, spikes per plant and seed weight, indicating the relative effectiveness of inter-population improvement to increase the frequencies of the favourable genes for these traits. Similar predominant variance due to non-additive genes for characters in castor was reported by Lavanya and Chandramohan (2003), and Solanki*et al*., (2004). Predominance of additive gene action in the expression of days to maturity and 100-seed weight, and prevalence of non-additive gene action in the expression of seed yield, length of main spike and capsules on primary spike were also described by Pathak *et al*. (1989). Ramesh *et al.* (2013) reported ratio of GCA variance and SCA variance in favour of high proportion of non-additive gene action for all the traits except plant height up to primary spike, nodes up to primary spike, number of capsules in the main spike and total length of secondary spike. The ratio of GCA variance and SCA variance was in favour of predominance of non-additive gene action for all the traits in castor, except number of nodes up to primary spike, 100 seed weight and seed oil content (Patel *et al.*, 2015).

Broad sense heritability (H^2) and narrow sense heritability (h^2) for all the studied traits are shown in Table 4. The broad sense heritability and narrow sense heritability ranged from 86.64 % to 99.90 % and 0.19 % to 67.78 % respectively among the traits studied. High heritability (> 60%) due to both narrow sense and broad sense were observed for 100 seed weight. Seed yield and seed oil content recorded low (h^2 < 30%) narrow sense heritability. Moderate (30% <h^2 < 60%) narrow sense heritability were observed for days to flowering, height at flowering, days to maturity, height at maturity, branches per plant and spikes per plant. This result gave insight on possible genetic progress and also indicated the level of environmental influence on the traits. The high heritability indicates least influence of environment and high possible selection progress, while the low heritability revealed high environmental influence. The results obtained in this study are comparable to the reports of Patel (1991), Servugaperumal *et al*. (2000) and Golakia *et al*. (2007).

Estimates of general combining ability (GCA) effects of the parents on all the studied traits are presented in Table 5. Three parents (P1, P5 and P6) showed significant positive GCA effects for seedling establishment. Significant desirable GCA effects for earliness to flowering and maturity were observed in P1. Highest significant GCA effects in a desirable direction for effective spike length and capsules per plant were recorded in P2. For seed weight, only P4, P5 and P6 showed significant positive GCA effects. P1, P4 and P5 recorded desirable effects for seed yield. Among all the parents, only P5 showed positive and significant GCA effects for both seed yield and seed oil content. These findings revealed the potentials of each of the parents in creating useful segregation populations with high frequency of desirable genes for each of the traits studied. Similar reports on GCA effects in castor have been made by Joshi *et al*. (2001) and Shivianna (2008). Furthermore, an efficient hybridization or breeding programme requires parents that are good combiners for a considerable number of desired characters. Therefore, it is important to assess the overall status of the parents with respect to their GCA effects over all the studied traits. The results of overall GCA status of the parents revealed that only parents P1 and P5 were the best overall general combiners for the traits under investigation (Table 6). This is evident from their high total scores (59 and 52 respectively). The implication of this result is that these parents combined their genes in a desired direction for most of the studied traits, suggesting their usefulness in castor improvement programme. Dobariya *et al*. (1992) reported two out of 12 castor parents to be best general combiners for yield and yield components. Saiyed (1992) reported six out of 10 castor parents to be high general combiners. Ramesh *et al.* (2013) detected one parent to be a good general combiner for most of the characters including seed yield. Golakia*et al.* (2015) observed two parents to be best combiners for earliness to maturity and seed yield per plant.

Specific combining ability (SCA) effects for days to flowering was positively significant in six out of 15 hybrids evaluated (Table 7). Three hybrids (P1×P2, P2×P5 and P3×P4) showed simultaneous significant negative SCA effects for both days to flowering and days to maturity (Table 7). For number of spikes per plant, six hybrids out of 15 showed significant SCA effects. Simultaneous significant positive SCA effects for both seed yield and seed oil content were observed in three hybrids. Eight hybrids were found to be good overall specific combiners (Table 8). These hybrids are P1×P2 (Score 100), P1×P3 (Score 106), P1×P4 (Score 114), P1×P5 (Score 101), P2×P6 (Score 106), P3×P4 (Score 125), P3×P6 (99) and P5×P6 (Score 124). These results revealed the possibility of obtaining promising segregating populations form the hybrids in the later generations. Similar findings to the present research have been documented by Mehta (2000) and Joshi *et al*. (2001). Ramesh *et al.* (2013) reported that the best performing hybrids with high mean seed yield and positive significant SCA effects for seed yield were generated from either high x average, high x high, average x average, average × high combiners for seed yield. The involvement of at least one good general combiner to generate good castor hybrid was reported by Mehta (2000), Lavanya and Chandramohan (2003) and Barad *et al.* (2009). Similar trend of results on overall specific combining ability in castor have been reported by Tank *et al.* (2003), Solanki *et al.* (2004) and Patel and Chauhan (2013).

Conclusion

The results revealed presence of sufficient genetic variability for the characters among the crosses. Both general combining ability (GCA) and specific combining ability (SCA) were found to be important for the inheritance of all the traits studied. Selection for improved seedling establishment, days to flowering, height at flowering, branches per plant, effective spike length, capsules per plant, seed yield and seed oil content within population may not be efficient because of high influence of non-additive genes actions on the traits, rather interpopulation improvement would be appropriate. Parent P1was found to be the best donor parent for development of early flowering and early maturing castor populations. Parent P2 would be useful when populations with high gene frequency for improved effective spike length and number of capsules per plant are required. Parent P1, P4 and P5 had desirable GCA effects for increased seed yield. The information provided in this research could be very useful in developing improved populations for castor breeding programme in Nigeria.

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Table 1. Individual and combined analysis of variance of crosses for 12 traits in 2016 and 2017

	Seedling Establishment (%)			**Days to 50% Flowering**			**Height at First Spike Flowering (cm)**		
Sources	**Year 1**	**Year 2**	**Combined**	**Year 1**	**Year 2**	**Combined**	**Year 1**	**Year 2**	**Combined**
Blocks	4.28	35.08	34.18	5.35	2.60	7.97	43.84	3.75	23.79
Crosses	353.69**	253.79**	583.80**	444.08**	494.96**	913.32**	1720.22**	1822.83**	3527.63**
Year (Y)			66.04			18.67			0.36
G x Y			23.68			5.72			15.42
Residuals	3.36	29.73	16.54	3.54	3.93	3.73	18.16	8.01	13.09
	Days to First Spike Maturity			**Height at First Spike Maturity (cm)**			**Branches Per Plant**		
Blocks	9.06	10.42	17.24	92.08	111.62	101.85	0.95	0.57	0.95
Crosses	913.94**	782.02**	1675.09**	3776.21**	3589.94**	7245.29**	4.26**	2.54**	6.34**
Year (Y)			4.44			4.01			8.10
G x Y			20.87			120.86			0.45
Residuals	16.35	8.44	12.39	126.80	84.24	105.52	0.41	0.19	0.30
	Number of Spikes per Plant			**Effective Spike Length (cm)**			**Number of Capsules per Spike**		
Blocks	3.48	0.42	3.95	13.54	2.95	8.24	8.00	4.86	4.43
Crosses	34.21**	42.02**	65.65**	154.19**	179.37**	301.51**	1135.97**	1363.48**	2292.09**
Year (Y)			8.10			3.17			22.30
G x Y			0.57			12.05*			7.37
Residuals	1.29	0.96	1.13	5.83	6.62	6.22	12.08	3.36	7.72
	100-Seed Weight (g)			**Seed Yield (kg/ha)**			**Percentage Seed Oil Content (%)**		
Blocks	1.01	2.83	0.92	1018.06	1179.59	848.83	14.56	1.62	8.09
Crosses	300.00**	331.56**	601.41**	630427.70**	649394.10**	1279241.00**	115.91**	132.92**	244.06**
Year (Y)			3.65			1971.16			10.61
G x Y			0.15			580.85			4.78
Residuals	1.77	2.96	0.87	286.80	410.45	348.62	8.51	8.09	8.30

Table 2. Combined Mean Values for 12 Traits among Six Castor Parents and their Hybrids in 2016 and 2017

Entries	ESTB	DF	HF	DM	HM	BPP	SPP	SL	CPS	SW	SY	SOC
P1	96.17	58.00	30.52	110.67	118.33	5.50	7.00	29.03	61.36	12.98	1054.13	27.83
P2	78.92	60.83	49.73	116.67	148.83	2.33	2.83	35.32	71.67	11.23	530.69	51.14
P3	89.72	68.33	38.78	114.83	112.17	4.33	6.17	27.00	35.64	15.77	631.52	32.65
P4	97.85	82.50	86.83	132.17	194.50	3.50	3.50	24.53	28.87	41.64	779.56	46.74
P5	95.67	66.83	64.19	124.17	172.00	4.83	4.83	26.70	53.33	15.58	665.20	50.24
P6	70.67	88.00	81.71	145.67	214.83	2.50	1.83	15.35	9.25	54.76	456.56	45.02
P1XP2	95.50	67.00	61.50	104.33	133.00	4.50	6.67	35.50	53.20	11.97	1285.34	54.09
P1XP3	94.99	70.17	39.59	102.00	161.33	3.67	7.33	28.17	55.64	14.36	1344.54	56.59
P1XP4	91.81	77.83	50.52	125.50	164.50	5.17	13.83	25.85	60.48	21.30	1820.02	46.12
P1XP5	90.44	67.67	47.83	113.83	167.33	4.33	11.67	34.60	50.93	14.90	1550.51	62.87
P1XP6	97.33	72.17	42.17	125.00	159.00	3.50	6.33	20.20	25.83	20.66	673.74	38.70
P2XP3	73.67	96.17	54.50	133.83	145.67	2.00	3.83	34.18	67.06	13.18	697.87	48.83
P2XP4	64.83	91.67	51.67	147.33	160.00	2.33	2.67	37.70	65.00	23.09	1165.26	58.08
P2XP5	98.17	69.83	65.17	103.17	141.83	2.50	3.00	29.57	36.33	16.21	762.25	59.55
P2XP6	94.00	96.83	80.83	143.50	179.33	1.50	2.50	44.00	88.42	22.38	1588.65	49.90
P3XP4	98.50	79.50	82.67	124.67	192.33	3.83	7.00	25.32	39.00	21.08	828.54	53.72
P3XP5	83.44	77.00	83.67	126.67	164.50	2.83	5.83	29.68	36.31	23.77	840.42	58.97
P3XP6	99.00	80.50	94.00	140.17	229.50	2.50	3.50	24.53	25.83	29.52	648.64	50.51
P4XP6	92.00	109.50	123.17	157.50	254.67	3.50	3.00	15.92	11.83	50.81	361.66	48.26
P5XP4	94.50	80.00	96.50	136.00	226.50	2.83	5.67	25.75	43.60	33.78	1805.98	45.83
P5XP6	98.00	80.00	90.83	137.83	180.00	4.17	8.00	29.52	34.00	30.35	1391.89	53.49
Mean	**91.08**	**81.06**	**70.97**	**128.09**	**177.30**	**3.28**	**6.06**	**29.37**	**46.23**	**23.16**	**1117.69**	**52.37**
HSD	**8.94**	**4.29**	**9.40**	**7.82**	**21.21**	**1.38**	**2.34**	**5.50**	**8.62**	**3.08**	**43.99**	**5.65**

ESTB – Seedling Establishment (%); DF – Days to first spike flowering; HF – Height at Flowering (cm); DM – Days to First Spike Maturity; HM - Height at Maturity (cm); BPP – Branches per Plant; SPP – Spikes per Plant; SL – Spike Length (cm); CPS – Capsules per Spike; SW – 100 Seed Weight (g); SY – Seed Yield per Plant (g); SOC – Seed Oil Content (%), HSD – Turkey's Honest Significant Difference

Table 3. Mean squares of General and Specific Combining Ability for all the traits studied in 2016 and 2017

	General Combining Ability (GCA)				**Specific Combining Ability (SCA)**			
Traits	**Year 1**	**Year 2**	**Combined**	**GCA x Y**	**Year 1**	**Year 2**	**Combined**	**GCA x Y**
ESTB	121.12	87.65	599.51**	26.81	116.10**	82.90**	575.07**	21.95
DF	275.36*	328.13**	1799.92**	10.56	77.28**	63.98**	420.76**	3.03
HF	1202.72*	1164.68*	7090.09**	12.14	223.78**	298.12**	1548.48**	17.24
DM	665.05**	566.17**	3669.29**	24.39	104.42**	90.95**	567.20**	18.91
HM	2769.80**	2526.64*	15686.38**	202.96	419.25**	457.76**	2555.79**	75.26
BPP	2.48	1.78*	12.32**	0.48	0.82**	0.32**	3.02**	0.44
SPP	22.87*	26.39**	135.42**	0.38	5.03**	4.16**	26.89**	0.68
SL	69.03	97.54	487.83**	11.89	41.59**	28.44**	197.99**	12.14
CPS	458.44	500.18	2869.41**	6.47	334.33**	305.40**	1971.35**	7.86
SW	230.64**	241.16**	1415.26**	0.16	30.19**	20.60**	149.27**	0.15
SY	213758.30	214913.20	1285584.00**	430.82	208133.80**	217326.60**	1375717.00**	664.20
SOC	53.06	50.47	307.49**	3.11	30.62**	40.88**	208.82**	5.70

ESTB – Seedling Establishment (%); DF – Days to first spike flowering; HF – Height at Flowering (cm); DM –Days to First Spike Maturity; HM - Height at Maturity (cm); BPP – Branches per Plant; SPP – Spikes per Plant; SL – Spike Length (cm); CPS – Capsules per Spike; SW – 100 Seed Weight (g); SY – Seed Yield per Plant (g); SOC – Seed Oil Content (%)

Table 4. Estimates of Genetic Variance Components for all Traits Studied in 2016 and 2017

	Additive Gene Variance (V_{add})				Non-additive Gene Variance (V_{dom})					
Parameters	**Year 1**	**Year 2**	**Combined**	$V_{add}\times$ **Y**	**Year 1**	**Year 2**	**Combined**	$V_{dom}\times$ **Y**	h^2 **(%)**	H^2**(%)**
ESTB	5.01	4.75	3.26	1.62	459.94	291.48	368.74	7.20	0.8	93.61
DF	198.07	264.15	228.60	2.50	304.42	250.97	278.48	0.01	44.53	98.78
HF	978.93	866.56	924.45	0.01	870.92	1182.18	1020.82	5.54	47.07	99.05
DM	560.63	475.22	516.10	1.83	395.88	352.37	365.52	8.69	57.06	97.47
HM	2350.55	2068.87	2167.14	42.56	1511.03	1716.30	1653.68	0.00	54.60	96.26
BPP	1.65	1.45	1.54	0.01	2.76	1.05	1.72	0.19	40.93	86.64
SPP	17.84	18.23	18.13	0.21	18.39	15.40	17.47	0.00	49.35	96.91
SL	27.43	69.09	48.34	0.30	158.61	105.29	123.89	7.89	25.94	92.42
CPS	124.10	174.78	149.90	0.00	1321.58	1297.35	1308.99	0.18	10.21	99.46
SW	209.44	212.55	210.99	0.01	99.82	97.14	99.41	0.21	67.78	99.71
SY	5624.51	2300.00	1683.34	0.00	832152.87	866459.26	850035.29	420.77	0.19	99.90
SOC	22.43	9.59	16.87	0.00	111.15	153.31	135.40	0.00	10.50	94.82

ESTB – Seedling Establishment (%); DF – Days to first spike flowering; HF – Height at Flowering (cm); DM – Days to First Spike Maturity; HM - Height at Maturity (cm); BPP – Branches per Plant; SPP – Spikes per Plant; SL – Spike Length (cm); CPS – Capsules per Spike; SW – 100 Seed Weight (g); SY – Seed Yield per Plant (g); SOC – Seed Oil Content (%)

Table 5. Estimates of General Combining Ability effects (gi) of each parent for 12 traits in castor

Parents	ESTB	DF	HF	DM	HM	BPP	SPP	SL	CPS	SW	SY	SOC
P1	3.66**	-12.61**	-28.31**	-17.44**	-25.33**	1.19**	3.89**	-0.63	3.73**	-8.14**	271.43**	-0.87
P2	-7.30**	4.05**	-10.30**	-2.06*	-31.67**	-0.89**	-2.90**	8.53**	19.71**	-7.24**	-22.26**	2.15**
P3	-1.44	-0.48	-0.11	-3.27**	1.71	-0.39**	-0.69**	-1.24*	-1.83**	-3.47**	-307.10**	1.69*
P4	-3.43**	8.30**	12.41**	12.63**	27.88**	0.32*	0.47*	-4.07**	-2.81**	8.57**	98.26**	-2.46**
P5	2.29*	-7.69**	7.28**	-5.73**	-1.58	0.07	0.97**	0.57	-7.49**	0.81**	190.65**	4.71**
P6	6.23**	8.43**	19.03**	15.88**	29.00**	-0.31*	-1.74**	-3.17**	-11.31**	9.48**	-230.96**	-5.24**
SE (*gi*)	0.75	0.36	0.67	0.66	1.91	0.10	0.20	0.46	0.52	0.17	3.48	0.54

ESTB – Seedling Establishment (%); DF – Days to first spike flowering; HF – Height at Flowering (cm); DM – Days to First Spike Maturity; HM - Height at Maturity (cm); BPP – Branches per Plant; SPP – Spikes per Plant; SL – Spike Length (cm); CPS – Capsules per Spike; SW – 100 Seed Weight (g); SY – Seed Yield per Plant (g); SOC – Seed Oil Content (%)

Table 6. Overall General Combining and Specific Combining Ability status of six parents and their hybrids for 12 characters in Castor

Parents	ESTB	DF	HF	DM	HM	BPP	SPP	SL	CPS	SW	SY	SOC	Total	Rank
P1	5	6	6	6	5	6	6	4	5	1	6	3	59	H
P2	1	3	5	3	6	1	1	6	6	2	3	5	42	L
P3	3	4	4	4	3	2	3	3	4	3	1	4	38	L
P4	2	2	2	2	2	5	4	1	3	5	4	2	34	L
P5	4	5	3	5	4	4	5	5	2	4	5	6	52	H
P6	6	1	1	1	1	3	2	2	1	6	2	1	27	L
Mean (Norm)													42	

ESTB – Seedling Establishment (%); DF – Days to first spike flowering; HF – Height at Flowering (cm); DM – Days to First Spike Maturity; HM - Height at Maturity (cm); BPP – Branches per Plant; SPP – Spikes per Plant; SL – Spike Length (cm); CPS – Capsules per Spike; SW – 100 Seed Weight (g); SY – Seed Yield per Plant (g); SOC – Seed Oil Content (%)

Table 7. Estimates of Specific Combining Ability effects (*gi*) of twelve traits in castor for 15 castor hybrids

Hybrids	ESTB	DF	HF	DM	HM	BPP	SPP	SL	CPS	SW	SY	SOC
P1×P2	8.05**	-5.50**	29.14**	-4.24**	12.70**	0.92**	-0.38	-1.77**	-16.48**	4.20**	-81.5**	0.43
P1×P3	1.68	2.20**	-2.95**	-5.36**	7.65**	-0.42**	-1.92**	0.67	13.33**	2.82**	262.52**	3.39**
P1×P4	0.49	1.08	-4.55**	2.21	-15.34**	0.38**	3.42**	1.19	7.51**	-2.28**	332.65**	-2.93**
P1×P5	-6.59**	6.91**	-2.10	8.92**	16.95**	-0.21	0.75**	5.29**	8.46**	-0.91**	-29.26**	6.65**
P1×P6	-3.64**	-4.70**	-19.52**	-1.53	-21.96**	-0.67**	-1.88**	-5.37**	-12.81**	-3.83**	-484.4**	-7.55**
P2×P3	-8.65**	11.54**	-6.06**	11.09**	-1.67	0.00	1.38**	-2.47**	2.94**	0.73**	-90.44**	-7.38**
P2×P4	-15.49**	-1.75**	-21.41**	8.67**	-13.50**	-0.38**	-0.96**	3.88**	1.87*	-1.40**	-28.41**	6.02**
P2×P5	12.1**	-7.58**	-2.78**	-17.11**	-2.21	0.04	-1.13**	-8.9**	-22.11**	-0.51	-523.82**	0.3
P2×P6	3.99**	3.29**	1.12	1.59	4.70	-0.58**	1.08**	9.27**	33.78**	-3.02**	724.18**	0.63
P3×P4	12.3**	-9.37**	-0.60	-12.78**	-14.55**	0.63**	1.17**	1.26	-2.59**	-7.17**	-80.30**	2.11**
P3×P5	-8.47**	4.12**	5.52**	7.59**	-12.92**	-0.13	-0.5	0.98	-0.59	3.27**	-160.81**	0.19
P3×P6	3.13**	-8.50**	4.10**	-0.53	21.49**	-0.08	-0.13	-0.43	-7.26**	0.35	69.03**	1.69*
P4×P5	4.56**	-1.66**	5.83**	1.01	22.9**	-0.83**	-1.83**	-0.11	7.67**	1.25**	399.38**	-8.79**
P4×P6	-1.87	11.7**	20.74**	0.88	20.49**	0.21**	-1.79**	-6.21**	-20.28**	9.6**	-623.31**	3.59**
P5×P6	-1.6	-1.79**	-6.45**	-0.41	-24.72**	1.12**	2.71**	2.74**	-11.31**	-3.10**	314.51**	1.65*
SE (Sii)	1.28	0.61	1.14	1.11	3.25	0.17	0.34	0.79	0.88	0.3	5.9	0.91

ESTB – Seedling Establishment (%); DF – Days to first spike flowering; HF – Height at Flowering (cm); DM – Days to First Spike Maturity; HM - Height at Maturity (cm); BPP – Branches per Plant; SPP – Spikes per Plant; SL – Spike Length (cm); CPS – Capsules per Spike; SW – 100 Seed Weight (g); SY – Seed Yield per Plant (g); SOC – Seed Oil Content (%)

Table 8. Overall General Combining and Specific Combining Ability status of six parents and their hybrids for 12 characters in castor

Hybrids	ESTB	DF	HF	DM	HM	BPP	SPP	SL	CPS	SW	SY	SOC	Total	Rank
P1×P2	13	12	1	12	5	14	8	5	3	14	6	7	100	H
P1×P3	9	6	10	13	6	4	1	8	14	12	11	12	106	H
P1×P4	8	7	11	5	13	12	15	10	11	5	13	4	114	H
P1×P5	4	3	8	2	4	6	10	14	13	7	8	15	94	L
P1×P6	5	11	14	11	14	2	2	3	4	2	3	2	73	L
P2×P3	2	2	12	1	8	9	13	4	10	10	5	3	79	L
P2×P4	1	9	15	3	11	5	6	13	9	6	9	14	101	H
P2×P5	14	13	9	15	9	10	5	1	1	8	2	6	93	L
P2×P6	11	5	6	6	7	3	11	15	15	4	15	8	106	H
P3×P4	15	15	7	14	12	13	12	11	7	1	7	11	125	H
P3×P5	3	4	4	4	10	7	7	9	8	13	4	5	78	L
P3×P6	10	14	5	10	2	8	9	6	6	9	10	10	99	H
P4×P5	12	8	3	7	1	1	3	7	12	11	14	1	80	L
P4×P6	6	1	2	8	3	11	4	2	2	15	1	13	68	L
P5×P6	7	10	13	9	15	15	14	12	5	3	12	9	124	H
Mean (Norm)													96	

ESTB – Seedling Establishment (%); DF – Days to first spike flowering; HF – Height at Flowering (cm); DM – Days to First Spike Maturity; HM - Height at Maturity (cm); BPP – Branches per Plant; SPP – Spikes per Plant; SL – Spike Length (cm); CPS – Capsules per Spike; SW – 100 Seed Weight (g); SY – Seed Yield per Plant (g); SOC – Seed Oil Content (%)