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Heterosis study for yield and yield attributes in castor (*Ricinus communis* L.)

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Abstract
A full diallel analysis was carried out by using five parents and their resulting 20 hybrids along with three check (GNCH-1, GCH-8 and GCH-9) of castor to estimate heterosis in the inheritance of majority of yield and yield contributing traits. The experiment was conducted in randomized block design with three replications at the college farm, N. M. College of Agriculture., N. A. U., Navsari during year 2019-20. The highest values of heterobeltiosis were 67.12% and standard heterosis were 38.98%, 32.37% and 33.66% over GNCH-1, GCH-8 and GCH-9 respectively for seed yield per plant in cross NAUCI-8 × NAUCI-7. Three cross combinations *viz.,* NAUCI-8 × NAUCI-7, NAUCI-6 × NAUCI-8 and NAUCI-9 × NAUCI-3 manifested significant and positive standard heterosis over checks GNCH-1, GCH-8 and GCH-9. The highest heterotic cross NAUCI-8 × NAUCI-7 also exhibited highest percentage of standard heterosis in desirable direction for yield attributing characters like secondary branches per plant, nodes up to primary spike, days to maturity and oil content (%).

Keywords: Replication, full diallel, hybrids, heterosis, heterobeltiosis

Introduction

Castor (*Ricinus communis* L., 2n = 2x = 20), is industrially important non-edible oilseed crop widely cultivated in the arid and semi-arid regions of the world (Govaerts *et al*., 2000) [3]. The crop has wide adaptability and is grown in tropical, sub-tropical and temperate regions of the world. It is cultivated in about 30 different countries on commercial scale, among these, India, Brazil, China, Russia, Thailand and Philippines are the principal castor growing countries. India is the largest castor producing country in the world, comprising about 70% of the world production, from an area of 8.24 lakh hectares with production 15.68 lakh tonne and average yield is 1902 kg/ha (Anon., 2018) [1]. Gujarat, Andhra Pradesh, Karnataka, Tamil Nadu, Orissa and Rajasthan are major castor growing states of the country. Among them, Gujarat is leading castor growing state, where the crop was grown in around 5.85 lakh ha with 13.33 lakh tonne production and productivity of 2279 kg/ha during 2017-18 (Anon., 2018) [1]. Castor seed contains 48 to 56 per cent oil. The castor oil does not freeze even under adverse temperature of -18 °C, therefore it is considered as best lubricating agent particularly for both high speed engines and aeroplanes. In castor, it's monoecious nature favours cross pollination and it is up to the extent of 50 per cent. Heterosis breeding has been a potential method of increasing yield in most of the cross-fertilizing crops. The present investigation was carried out to identify superior hybrids based on better parent and standard heterosis.

Materials and Methods

The experimental material comprised of 5 parental lines *viz.*, NAUCI-3, NAUCI-6, NAUCI-7, NAUCI-8 NAUCI-9, as well as 20 crosses and 3 checks *viz.*, GNCH-1, GCH-8, GCH-9, were evaluated in a randomized block design with three replications using full diallel at college farm, N. A. U., Navsari during year 2019-20. The observations were recorded on five randomly selected plants from parents and crosses for ten characters *viz.*, days to 50% flowering, days to maturity, plant height (cm), nodes up to primary spike, effective length of primary spike (cm), secondary branches per plant, capsules per primary spike, 100 seed weight (g), seed yield per plant (g) and oil content (%). The mean performance of parents, as well as hybrids, were subjected to statistical analysis. Analysis of variance was carried out to test the significance for each character as per the methodology suggested by Panse and

Sukhatme (1985) [5]. Heterobeltiosis (BH) was calculated using the method given by Fonseca and Patterson (1968) [2]. and Standard heterosis by Meredith and Bridge (1972) [4].

Results and Discussion

Analysis of variance depicting mean sum of squares for ten quantitative traits is presented in Table 1. The analysis of variance showed significant differences among the genotypes for all the traits revealed that the considerable amount of variability was observed among experimental material. This validated that the material was appropriate for present study. The genotypic variance was further partitioned into parents, hybrids and parents *vs* hybrids. The differences among parents highly significant for all characters under investigation except days to 50% flowering, days to maturity, plant height, nodes upto primary spike, and oil content and hybrids were also found highly significant for all characters except nodes up to primary spike and effective length of primary spike, which were significant. Differences due to parents *vs* hybrids were found non- significant for all the traits under study except plant height, and capsules per primary spike which are highly significant. The hybrid NAUCI-6 × NAUCI-8 exhibited the highest desirable standard heterosis over all three checks and it exhibited the second highest desirable heterobeltosis for days to 50% flowering. Among 20 crosses, none of the crosses exhibited significant heterobeltiosis, while desirable standard heterosis were observed in 5 crosses and 2 crosses over the checks GNCH-1 and GCH-8, respectively for days to maturity. The negative heterosis is desirable for plant height. Only 1 hybrid (NAUCI-9 × NAUCI-6) registered significant and negative heterobeltiosis for plant height. The hybrid NAUCI-9 × NAUCI-6 exhibited lowest standard heterosis over all three checks for plant height character. For nodes up to primary spike, hybrid NAUCI-8 × NAUCI-7 exhibited significant heterobeltiosis and standard heterosis in desirable direction over all three checks. None of hybrids showed significant positive heterobeltiosis but the hybrid NAUCI-6 × NAUCI-8 exhibited highest standard heterosis over all three checks for effective length of primary spike. For secondary branches per plant, out of 20 hybrids, 3 hybrids NAUCI-9 × NAUCI-3 (46.60%), NAUCI-6 × NAUCI-3 (42.09%) and NAUCI-8 × NAUCI-7 (30.28%) registered for significant heterobeltiosis in desirable direction and hybrid NAUCI-8 × NAUCI-7 exhibited highest standard heterosis over the all three checks. For capsules per primary spike**,** out of 20 hybrids, 3 hybrids registered significant heterobeltiosis in desirable direction and the hybrid NAUCI-6 × NAUCI-8 exhibited highest standard heterosis over the all three checks. The hybrid NAUCI-9 × NAUCI-3 (5.15%) exhibited highest heterobeltiosis followed by NAUCI-3 × NAUCI-7 and NAUCI-7 × NAUCI-9 with 3.09%, While hybrid NAUCI-6 × NAUCI-3 and NAUCI-6 × NAUCI-8 exhibited highest standard heterosis over the all three checks for 100 seed weight. For oil content hybrid NAUCI-8 × NAUCI-7 (3.19%) registered for highest heterobeltiosis followed by NAUCI-9 × NAUCI-3 (2.69%) and NAUCI-9 × NAUCI-8 (1.71%), while NAUCI-8 × NAUCI-7 exhibited highest standard heterosis over all three checks.

Seed yield is the economic important trait and breeders attempt to evolve varieties/hybrids with high seed yield. The positive heterosis is desirable for seed yield per plant. The result revealed that the heterobeltiosis ranged from -47.28% (NAUCI-6 × NAUCI 9) to 67.12% (NAUCI-8 × NAUCI-7). Out of 20 hybrids, 4 hybrids registered for highly significant and positive heterobeltiosis. NAUCI-8 × NAUCI-7 exhibited highest heterobeltiosis followed by NAUCI-9 × NAUCI-3 (59.30%) and NAUCI-6 × NAUCI-8 (32.44%). The standard heterosis over GNCH-1 varied from -54.51% (NAUCI-8 × NAUCI-3) to 38.98% (NAUCI-8 × NAUCI-7). Among the 20 hybrids 4 hybrids registered for highly significant and positive standard heterosis. The hybrid NAUCI-8 × NAUCI-7 (38.98%) exhibited highest standard heterosis over GNCH-1 followed by NAUCI-6 × NAUCI-8 (30.81%) and NAUCI-9 × NAUCI-3 (28.08%). The standard heterosis over GCH-8 varied from -56.68% (NAUCI-8 × NAUCI-3) to 32.37% (NAUCI-8 × NAUCI-7). Total 3 hybrids out of 20 hybrids showed significant positive standard heterosis over GCH-8. Hybrid NAUCI-8 × NAUCI-7 (32.37%) exhibited highest standard heterosis over GCH-8 followed by NAUCI-6 × NAUCI-8 (24.59%) and NAUCI-9 × NAUCI-3 (21.99%). The standard heterosis over GCH-9 varied from -56.25% (NAUCI-8 × NAUCI-3) to 33.66% (NAUCI-8 × NAUCI-7). Total 3 hybrids out of 20 hybrids showed significant positive standard heterosis over GCH-9. Hybrid NAUCI-8 × NAUCI-7 (33.66%) exhibited highest standard heterosis over GCH-9 followed by NAUCI-6 × NAUCI-8 (25.80%) and NAUCI-9 × NAUCI-3 (23.18%). The hybrid NAUCI-8 × NAUCI-7 exhibited highest standard heterosis over the all three checks.

The *per se* performance of top three crosses along with standard heterosis and better parent heterosis for seed yield and the yield attributing traits which registered significant and desirable standard heterosis for the particular cross is summarized in Table 6. It was noted that the top ranking crosses based on *per se* performance and standard heterosis were almost same, whereas ranking based on heterobeltiosis and *per se* performance varied slightly. This indicated that ranking based on standard heterosis is more reliable as compared to better parent heterosis.

Table 1: Analysis of variance (mean sum of square) for experimental design for different traits in castor

Source of variation	df	Days to 50% flowering	Days to maturity	Plant height (cm)	Nodes up to primary spike	Effective length of primary spike (cm)
Replication	2	1.84	47.45	976.46	9.28	197.48
Treatments	24	28.23**	69.49**	1080.62**	6.63**	231.89**
Parents	4	15.43	49.66	446.89	4.59	574.69**
Hybrids	19	31.47**	76.52**	1166.04**	7.37*	171.57*
Parent *vs* Hybrids	1	17.89	15.28	1992.54**	5.36	6.89
F1's	9	35.21**	93.05**	470.90	1.48	158.68
Reciprocals	9	25.14**	66.25**	1886.39**	13.99**	202.96*
F1 *vs* Reciprocals	1	54.76*	20.22	939.08	0.81	5.11
Error	48	8.67	21.54	237.31	3.71	93.82
Total	74	14.83	37.79	530.80	4.87	141.40

* and ** indicates significance at 5% and 1% levels of probability, respectively

Source of variation	Df	Secondary branches per plant	Capsules per primary spike	100 seed weight (g)	Seed yield per plant (g)	Oil content (%)
Replication	2	0.34	23.97	1.36	802.89	0.70
Treatments	24	12.56**	752.81**	6.43**	8036.60**	6.63**
Parents	4	9.21**	929.63**	5.40**	2263.96**	3.11
Hybrids	19	13.89**	649.30**	6.93**	9662.34**	7.65**
Parent *vs* Hybrids	1	0.68	2012.22**	1.06	238.06	1.42
F1's	9	8.88**	555.54**	3.69*	7371.24**	5.02*
Reciprocals	9	19.82**	754.22**	10.94**	13013.09**	9.56**
F1 *vs* Reciprocals	1	5.61*	548.92*	0.08	125.51	14.05*
Error	48	0.94	86.56	1.33	356.66	1.99
Total	74	4.69	300.95	2.99	2859.51	3.46

* and ** indicates significance at 5% and 1% levels of probability, respectively

Table 2: Percent heterobeltiosis (H_1) and standard heterosis (H_2) for days to 50% flowering, days to maturity and plant height (cm) in castor

Sr. No.	Crosses	Days to 50% flowering				Days to maturity				Plant height (cm)			
		H_1 (%)	H_2 (%)			H_1 (%)	H_2 (%)			H_1 (%)	H_2 (%)		
			SC-1	SC-2	SC-3		SC-1	SC-2	SC_3		SC-1	SC-2	SC-3
1	NAUCI-3 × NAUCI-6	0.51	1.20	4.79	5.49	0.80	-5.08	2.04	7.67	-7.53	64.90**	-19.72	-3.72
2	NAUCI-3 × NAUCI-7	7.62	8.91*	12.77**	13.52**	-0.10	-5.15	1.96	7.59	8.11	85.30**	-9.79	8.19
3	NAUCI-3 × NAUCI-8	10.58**	7.37	11.17**	11.92**	0.14	-7.69*	-0.77	4.71	18.06	113.56**	3.97	24.69
4	NAUCI-3 × NAUCI-9	-2.38	-0.70	2.81	3.50	2.81	-2.40	4.92	10.72**	6.28	92.24**	-6.41	12.24
5	NAUCI-6 × NAUCI-3	-0.52	0.17	3.72	4.41	-0.81	-6.60	0.40	5.94	4.04	85.54**	-9.67	8.33
6	NAUCI-6 × NAUCI-7	7.65	8.40*	12.24**	12.99**	1.38	-4.54	2.62	8.28*	15.89	98.62**	-3.30	15.97
7	NAUCI-6 × NAUCI-8	-3.70	-6.50	-3.19	-2.54	-6.86	-14.15**	-7.71*	-2.62	7.07	90.95**	-7.04	11.49
8	NAUCI-6 × NAUCI-9	8.16	8.91*	12.77**	13.52**	1.48	-4.45	2.72	8.39*	15.62	106.20**	0.39	20.39
9	NAUCI-7 × NAUCI-3	-1.02	0.17	3.72	4.42	-1.88	-6.85	0.14	5.66	27.66*	118.79**	6.52	27.75*
10	NAUCI-7 × NAUCI-6	1.53	2.23	5.85	6.56	3.32	-2.71	4.59	10.36**	23.19	111.14**	2.79	23.28

* and ** indicates significance at 5% and 1% levels of probability, respectively

Sr. No.	Crosses	Days to 50% flowering				Days to maturity				Plant height (cm)			
		H_1 (%)	H_2 (%)			H_1 (%)	H_2 (%)			H_1 (%)	H_2 (%)		
			SC-1	SC-2	SC-3		SC-1	SC-2	SC-3		SC-1	SC-2	SC-3
11	NAUCI-7 × NAUCI-8	7.41	4.29	7.98	8.70	10.49**	1.84	9.48**	15.53**	15.98	98.78**	-3.22	16.06
12	NAUCI-7 × NAUCI-9	6.60	7.88	11.70**	12.45**	5.21	0.98	8.56*	14.55**	29.47*	121.90**	8.03	29.56*
13	NAUCI-8 × NAUCI-3	10.58**	7.37	11.17**	11.92**	0.98	-6.92	0.06	5.58	37.13**	148.06**	20.77	44.84**
14	NAUCI-8 × NAUCI-6	13.23**	9.94*	13.83**	14.59**	4.41	-3.77	3.45	9.16*	40.05**	149.76**	21.59*	45.83**
15	NAUCI-8 × NAUCI-7	-3.18	-6.00	-2.67	-2.01	-7.04	-14.31**	-7.89*	-2.80	18.64	103.34**	-1.00	18.73
16	NAUCI-8 × NAUCI-9	12.17**	8.91*	12.77**	13.52**	0.65	-7.23*	-0.27	5.24	26.69*	132.68**	13.28	35.86**
17	NAUCI-9 × NAUCI-3	-3.54	-1.88	1.60	2.28	-3.32	-8.22*	-1.33	4.11	6.23	92.15**	-6.45	12.19
18	NAUCI-9 × NAUCI-6	2.55	3.26	6.92	7.63	5.51	-0.65	6.80	12.69**	-28.61*	27.31	-38.02**	-25.67*
19	NAUCI-9 × NAUCI-7	0.50	1.71	5.31	6.02	-0.48	-4.47	2.69	8.36*	47.46**	152.74**	23.04*	47.57**
20	NAUCI-9 × NAUCI-8	5.29	2.23	5.85	6.56	5.43	-2.82	4.47	10.23**	29.77**	138.34**	16.04	39.16**
	SE (d) ±	2.40	2.40	2.40	2.40	3.79	3.79	3.79	3.79	12.58	12.58	12.58	12.58

* and ** indicates significance at 5% and 1% levels of probability, respectively

Table 3: Percent heterobeltiosis (H_1) and standard heterosis (H_2) for nodes up to primary spike, effective length of primary spike (cm) and secondary branches per plant in castor

Sr. No.	Crosses	Nodes up to primary spike				Effective length of primary spike (cm)				Secondary branches per plant			
		H_1 (%)	H_2 (%)			H_1 (%)	H_2 (%)			H_1 (%)	H_2 (%)		
			SC-1	SC-2	SC-3		SC-1	SC-2	SC_3		SC-1	SC-2	SC-3
1	NAUCI-3 × NAUCI-6	8.29	1.28	-5.93	-2.63	8.79	-7.17	32.99	8.10	0.31	-9.88	-31.67**	-28.91**
2	NAUCI-3 × NAUCI-7	2.58	1.64	-5.59	-2.28	-18.63	-7.52	32.49	7.69	-1.24	0.85	-23.54**	-20.45*
3	NAUCI-3 × NAUCI-8	6.45	5.47	-2.03	1.40	-6.26	-12.32	25.60	2.10	-38.35**	-20.60	-39.80**	-37.37**
4	NAUCI-3 × NAUCI-9	14.76	9.95	2.12	5.70	-0.95	5.10	50.57**	22.40	-9.84	-19.00	-38.59**	-36.10**
5	NAUCI-6 × NAUCI-3	13.95	6.57	-1.02	2.46	-1.30	-15.77	20.66	-1.92	42.09**	27.66*	-3.21	0.71
6	NAUCI-6 × NAUCI-7	13.56	6.20	-1.36	2.11	-28.37**	-18.60	16.62	-5.20	-37.45**	-36.12**	-51.57**	-49.61**
7	NAUCI-6 × NAUCI-8	3.02	-3.65	-10.51	-7.37	23.44	15.46	65.40**	34.45*	11.40	43.46**	8.77	13.17
8	NAUCI-6 × NAUCI-9	10.83	3.65	-3.73	-0.35	-18.39	-13.40	24.06	0.85	-20.99	-30.57**	-47.36**	-45.23**
9	NAUCI-7 × NAUCI-3	20.81*	19.71*	11.19	15.09	-23.33*	-12.86	24.83	1.47	-29.80**	-28.32*	-45.65**	-43.45**
10	NAUCI-7 × NAUCI-6	6.83	-0.09	-7.20	-3.95	-28.35**	-18.57	16.65	-5.18	-27.50*	-25.96*	-43.87**	-41.60**

* and ** indicates significance at 5% and 1% levels of probability, respectively

Sr. No.	Crosses	Nodes up to primary spike				Effective length of primary spike (cm)				Secondary branches per plant			
		H_1 (%)	H_2 (%)			H_1 (%)	H_2 (%)			H_1 (%)	H_2 (%)		
			SC-1	SC-2	SC-3		SC-1	SC-2	SC-3		SC-1	SC-2	SC-3
11	NAUCI-7 × NAUCI-8	3.74	4.74	-2.71	0.70	-19.37	-8.36	31.28	6.71	-54.35**	-41.20**	-55.42**	-53.62**
12	NAUCI-7 × NAUCI-9	7.30	2.79	-4.53	-1.18	-17.25	-5.95	34.73	9.52	-4.84	-2.82	-26.32**	-23.34*
13	NAUCI-8 × NAUCI-3	19.89*	18.80	10.34	14.21	-2.54	-8.85	30.59	6.15	-18.66	4.75	-20.58*	-17.37
14	NAUCI-8 × NAUCI-6	17.46	9.85	2.03	5.61	-9.56	-15.41	21.18	-1.49	-45.73**	-30.10**	-47.00**	-44.86**
15	NAUCI-8 × NAUCI-7	-22.28*	-21.53*	-27.12**	-24.56**	-4.29	8.78	55.84**	26.68	30.28**	67.78**	27.21**	32.36**
16	NAUCI-8 × NAUCI-9	3.33	-1.00	-8.05	-4.82	-22.80	-18.08	17.36	-4.60	-39.66**	-22.30	-41.08**	-38.70**
17	NAUCI-9 × NAUCI-3	1.20	-3.05	-9.95	-6.79	8.23	14.84	64.52**	33.73*	46.60**	31.70**	-0.14	3.90
18	NAUCI-9 × NAUCI-6	10.97	3.78	-3.61	-0.23	-15.47	-10.30	28.50	4.45	-29.12*	-37.72**	-52.78**	-50.87**
19	NAUCI-9 × NAUCI-7	5.24	0.82	-6.36	-3.07	-6.13	6.69	52.84**	24.24	-34.73**	-33.35**	-49.47**	-47.42**
20	NAUCI-9 × NAUCI-8	13.68	8.91	1.15	4.70	-16.13	-11.01	27.49	3.63	-44.34**	-28.32*	-45.65**	-43.45**
	SE (d) ±	1.57	1.57	1.57	1.57	7.91	7.91	7.91	7.91	0.79	0.79	0.79	0.79

* and ** indicates significance at 5% and 1% levels of probability, respectively

Table 4: Percent heterobeltiosis (H_1) and standard heterosis (H_2) for capsules per primary spike and 100 seed weight (g) in castor

Sr. No.	Crosses	Capsules per primary spike				100 seed weight (g)			
		H_1 (%)	H_2 (%)			H_1 (%)	H_2 (%)		
			SC-1	SC-2	SC-3		SC-1	SC-2	SC-3
1	NAUCI-3 × NAUCI-6	-7.94	-37.85**	-22.12	-40.42**	-6.80*	-1.03	-9.43**	-4.95
2	NAUCI-3 × NAUCI-7	1.94	7.49	34.69**	3.05	3.09	3.09	-5.66	-0.99
3	NAUCI-3 × NAUCI-8	4.94	1.79	27.54	-2.42	-6.80*	-1.03	-9.43**	-4.95
4	NAUCI-3 × NAUCI-9	2.19	-2.31	22.41	-6.35	-2.06	-2.06	-10.38**	-5.94
5	NAUCI-6 × NAUCI-3	75.74**	18.64	48.67**	13.74	1.94	8.25**	-0.94	3.96
6	NAUCI-6 × NAUCI-7	1.86	7.40	34.58**	2.96	-6.80*	-1.03	-9.43**	-4.95
7	NAUCI-6 × NAUCI-8	32.77**	28.78**	61.37**	23.45*	1.94	8.25**	-0.94	3.96
8	NAUCI-6 × NAUCI-9	-3.93	-8.16	15.08	-11.95	-7.77**	-2.06	-10.38**	-5.94
9	NAUCI-7 × NAUCI-3	19.62	26.13*	58.05**	20.92	-3.09	-3.09	-11.32**	-6.93*
10	NAUCI-7 × NAUCI-6	-27.63**	-23.69*	-4.38	-26.85**	-1.94	4.12	-4.72	0.00
11	NAUCI-7 × NAUCI-8	-14.55	-9.90	12.90	-13.62	-2.91	3.09	-5.66	-0.99
12	NAUCI-7 × NAUCI-9	-8.66	-3.69	20.68	-7.67	3.09	3.09	-5.66	-0.99
13	NAUCI-8 × NAUCI-3	-18.01	-20.47	-0.34	-23.76*	-12.62**	-7.22*	-15.09**	-10.89**
14	NAUCI-8 × NAUCI-6	9.21	5.92	32.73*	1.54	-3.40	2.58	-6.13*	-1.49
15	NAUCI-8 × NAUCI-7	12.85	18.99	49.10**	14.07	1.66	7.95**	-1.22	3.67
16	NAUCI-8 × NAUCI-9	-18.14	-20.60	-0.51	-23.88*	-7.77**	-2.06	-10.38**	-5.94
17	NAUCI-9 × NAUCI-3	31.89**	26.09*	58.00**	20.88	5.15	5.15	-3.77	0.99
18	NAUCI-9 × NAUCI-6	-24.65*	-27.96**	-9.73	-30.94**	-1.94	4.12	-4.72	0.00
19	NAUCI-9 × NAUCI-7	2.58	8.17	35.54**	3.70	-5.15	-5.15	-13.21**	-8.91**
20	NAUCI-9 × NAUCI-8	13.59	10.18	38.06**	5.62	-11.65**	-6.19	-14.15**	-9.90**
	SE (d) ±	7.60	7.60	7.60	7.60	0.94	0.94	0.94	0.94

* and ** indicates significance at 5% and 1% levels of probability, respectively

Table 5: Percent heterobeltiosis (H_1) and standard heterosis (H_2) for seed yield per plant (g) and oil content % in castor

Sr. No.	Crosses	Seed yield per plant (g)				Oil content (%)			
		H_1 (%)	H_2 (%)			H_1 (%)	H_2 (%)		
			SC-1	SC-2	SC-3		SC-1	SC-2	SC-3
1	NAUCI-3 × NAUCI-6	-24.60**	-25.53**	-29.08**	-28.38**	-2.69	-1.35	-4.65	-2.65
2	NAUCI-3 × NAUCI-7	21.35	-5.91	-10.38	-9.51	-3.32	-1.98	-5.26	-3.28
3	NAUCI-3 × NAUCI-8	-11.17	-26.13**	-29.64**	-28.96**	-1.63	-0.28	-3.61	-1.59
4	NAUCI-3 × NAUCI-9	-1.15	-20.52*	-24.30**	-23.57**	-6.57**	-5.28	-8.45**	-6.53**
5	NAUCI-6 × NAUCI-3	24.16**	22.63**	16.80	17.94	0.69	2.08	-1.33	0.73
6	NAUCI-6 × NAUCI-7	18.65	17.18	11.61	12.70	1.09	2.20	-1.22	0.85
7	NAUCI-6 × NAUCI-8	32.44**	30.81**	24.59**	25.80**	0.41	-0.16	-3.49	-1.47
8	NAUCI-6 × NAUCI-9	-47.28**	-47.93**	-50.41**	-49.93**	-6.01*	-6.54*	-9.66**	-7.78**
9	NAUCI-7 × NAUCI-3	-38.40**	-52.23**	-54.51**	-54.06**	-2.15	-0.80	-4.12	-2.11
10	NAUCI-7 × NAUCI-6	-21.04*	-22.01*	-25.72**	-25.00**	-8.77**	-7.77**	-10.85**	-8.99**
11	NAUCI-7 × NAUCI-8	-33.30**	-44.53**	-47.17**	-46.65**	-3.45	-2.40	-5.66*	-3.68
12	NAUCI-7 × NAUCI-9	3.88	-16.47	-20.45*	-19.67*	-4.97	-3.93	-7.14**	-5.19
13	NAUCI-8 × NAUCI-3	-45.30**	-54.51**	-56.68**	-56.25**	-0.06	1.32	-2.07	-0.02
14	NAUCI-8 × NAUCI-6	-43.72**	-44.42**	-47.06**	-46.54**	-2.67	-3.23	-6.46**	-4.51
15	NAUCI-8 × NAUCI-7	67.12**	38.98**	32.37**	33.66**	3.19	4.32	0.84	2.95
16	NAUCI-8 × NAUCI-9	-40.94**	-50.88**	-53.22**	-52.77**	-3.74	-5.39	-8.55**	-6.64**
17	NAUCI-9 × NAUCI-3	59.30**	28.08**	21.99**	23.18**	2.69	4.11	0.63	2.74
18	NAUCI-9 × NAUCI-6	-27.56**	-28.45**	-31.86**	-31.19**	0.53	-0.04	-3.38	-1.36
19	NAUCI-9 × NAUCI-7	12.16	-9.82	-14.11	-13.27	-5.44	-4.41	-7.60**	-5.67*
20	NAUCI-9 × NAUCI-8	-42.77**	-52.41**	-54.67**	-54.23**	1.71	-0.04	-3.38	-1.35
	SE (d) ±	15.42	15.42	15.42	15.42	1.15	1.15	1.15	1.15

* and ** indicates significance at 5% and 1% levels of probability, respectively

Table 6: Best heterotic crosses and their performance for seed yield per plant and related parameters in castor

Best crosses ($P_1 \times P_2$)	Mean yield/plant (g)	Better parent heterosis (%)	Standard heterosis (%)			Significant standard heterosis (over the all 3 checks) of other traits in desired direction
			SC-1	SC-2	SC-3	
NAUCI-8 × NAUCI-7	255.00	67.12**	38.98**	32.37**	33.66**	Nodes up to primary spike, secondary branches per plant
NAUCI-6 × NAUCI-8	240.00	32.44**	30.81**	24.59**	25.80**	Capsule per primary spike
NAUCI-9 × NAUCI-3	235.00	59.30**	28.08**	21.99**	23.18**	Capsule per primary spike

* and ** indicates significance at 5% and 1% levels of probability, respectively

Table 7: Range of heterobeltiosis (H_1) and standard heterosis (H_2) as well as number of crosses with significant heterotic effects for various characters in castor

Sr. No.	Characters	Range of heterosis (%)							Number of crosses with significant heterosis			
		Heterobeltiosis (%)			Standard heterosis (%)				H_1 (%)		H_2 (%)	
									+Ve	-Ve	+Ve	-Ve
1.	Days to 50% flowering	-3.70	to	13.23	SC-1	-6.50	to	9.94	4	0	5	0
					SC-2	-3.19	to	13.83			8	0
					SC-3	-2.54	to	14.59			8	0
2.	Days to maturity	-7.04	to	10.49	SC-1	-14.31	to	1.84	1	0	0	5
					SC-2	-7.89	to	9.48			2	2
					SC-3	-2.80	to	15.53			10	0
3.	Plant height (cm)	-28.61	to	47.46	SC-1	27.31	to	152.74	7	1	19	0
					SC-2	-38.02	to	23.04			2	1
					SC-3	-25.67	to	47.57			6	1
4.	Nodes up to primary spike	-22.28	to	20.81	SC-1	-21.53	to	19.71	2	1	1	1
					SC-2	-27.12	to	11.19			0	1
					SC-3	-24.56	to	15.09			0	1
5.	Effective length of primary spike	-28.37	to	23.44	SC-1	-18.60	to	15.46	0	3	0	0
					SC-2	16.62	to	65.40			5	0
					SC-3	-5.20	to	34.45			2	0

Sr. No.	Characters	Range of heterosis (%)								Number of crosses with significant heterosis			
		Heterobeltiosis (%)			Standard heterosis (%)					H_1 (%)		H_2 (%)	
										+Ve	-Ve	+Ve	-Ve
6.	Secondary branches per plant	-54.35	to	46.60	SC-1	-41.20		67.78		3	10	4	9
					SC-2	-55.42	to	27.21				1	16
					SC-3	-53.62		32.36				1	15
7.	Capsules per primary spike	-27.63	to	75.74	SC-1	-37.85		28.78		3	2	3	3
					SC-2	-22.12	to	61.37				10	0
					SC-3	-40.42		23.45				1	5
8.	100 seed weight (cm)	-12.62	to	5.15	SC-1	-7.22		8.25		0	7	3	1
					SC-2	-15.09	to	-0.94				0	11
					SC-3	-10.89		3.96				0	4
9.	Seed yield per plant	-47.28	to	67.12	SC-1	-54.51		38.98		4	10	4	12
					SC-2	-56.68	to	32.37				3	13
					SC-3	-56.25		33.66				3	13
10.	Oil content (%)	-8.77	to	3.19	SC-1	-7.77		4.32		0	3	0	2
					SC-2	-10.85	to	0.84				0	8
					SC-3	-8.99		2.95				0	5

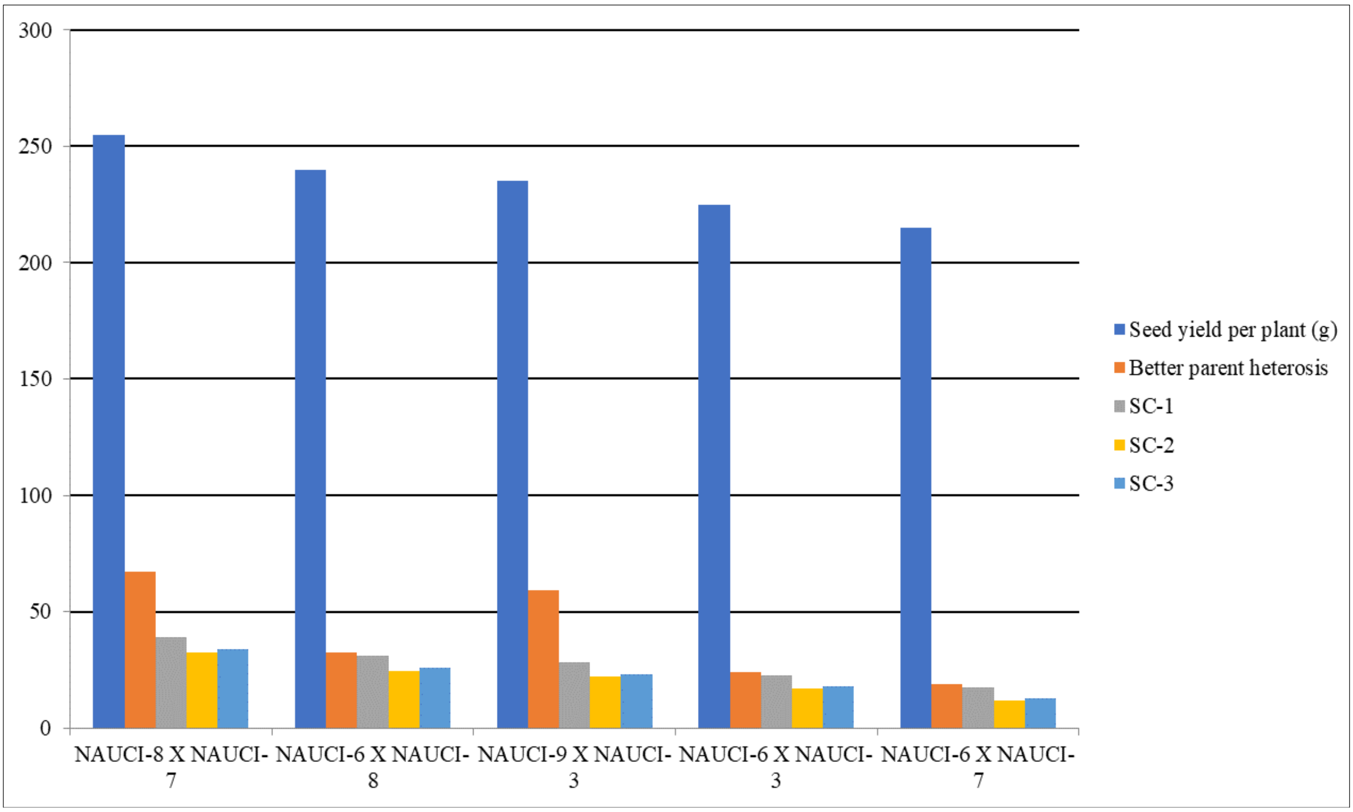

Fig 1: The top five crosses in terms of *per se* performance along with better parent heterosis and standard heterosis for seed yield in castor

Conclusion

In conclusion, the analysis of variance conducted on ten quantitative traits demonstrated significant differences among genotypes, indicating substantial variability within the experimental material. Further partitioning of genotypic variance into parents, hybrids, and parent versus hybrid categories revealed significant distinctions, particularly in traits such as plant height, capsules per primary spike, and seed yield, which are economically significant. Several hybrids exhibited desirable standard heterosis over the checks, with notable performances in traits like seed yield per plant. Notably, the top-ranking crosses based on per se performance closely aligned with those based on standard heterosis, suggesting the reliability of the latter for assessing breeding outcomes. These findings underscore the potential for developing high-yielding varieties through hybridization strategies, providing valuable insights for breeders aiming to enhance crop productivity and economic returns.

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