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Heterosis for seed yield and its contributing characters in castor [*Ricinus communis* L.]

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Abstract
The phenomenon of heterosis has provided the most important genetic tools in improving yield of crop plants. Identification of specific parental combination capable of producing the highest level of heterotic effects in F_1 has immense value for commercial exploitation of heterosis. The experimental material comprising 10 inbred lines, their resultant 45 cross combinations and one standard check GCH 7 was evaluated in a randomized complete block design with three replications at Agronomy farm, B. A. College of Agriculture, A. A. U., Anand. The estimates of heterosis revealed that 32 and 23 crosses manifested significant positive relative heterosis and heterobeltiosis, respectively for seed yield per plant. Whereas, none of the crosses showed significant positive standard heterosis. The hybrid SH 1 x PCS 124 expressed the highest relative heterosis and heterobeltiosis (63.58% and 57.68%) followed by SKI 324 x VH 63-1-3 (59.62%, and 57.49%), ANDCI 8 x SH 1 (57.47% and 48.08%) and SH 42 x PCS 124 (55.44% and 52.83%), respectively.

Keywords: castor, heterobeltiosis, standard heterosis, seed yield

Introduction

Castor (*Ricinus communis* L., 2n = 2x = 20) is an industrially important non-edible oilseed crop widely cultivated in the arid and semi-arid regions of the world. Castor belongs to monospecific genus *Ricinus* of Euphorbiaceae family. Castor seed contains 48 to 56 per cent oil of tremendous industrial value and it is mainly utilized in the production of soaps, perfumed hair oil, printing inks, varnishes, synthetic resins, carbon paper, lubricant, ointments, other cosmetics and processed leather etc. Castor oil is the source of sebacic acid which is used in the manufacture of nylon and vinyl resins (Nagraj, 1996) [5]. In India, total area under castor crop during 2016-17 was 8.3 lakh ha with production of 14.21 lakh tonne and productivity of 1713 kg/ha (Anonymous, 2018) [1]. India contributes about 65 per cent of the world production and meets about 90 per cent world castor oil demands.

Nature and magnitude of heterosis is one of the important aspects for selection of the right parents for crosses and also help in identification of superior cross combinations that may produce desirable transgressive segregants in advanced generations. The choice of parents to be incorporated in hybridization programme is a crucial step for breeders, particularly if the aim is to improve the complex quantitative characters such as yield and its components. The use of parents of known superior genetic worth ensures much better success. It requires extensive and detailed genetic assessment of existing germplasm as well as newly developed promising genotype, which could be used in future breeding programme or could be directly released as a cultivar after thorough testing.

Materials and Methods

Experimental material of the present study included 56 test entries comprising of ten inbred lines of castor (ANDCI 10-6, ANDCI 10-7, ANDCI 8, JI 358, SH 42, SH 1, SKI 324, VH 63-1-3, PCS 124 and JH 109) and 45 resultant hybrids along with one standard check hybrid 'GCH-7'. These inbreds were crossed in diallel fashion, excluding reciprocals during *rabi* 2014-15 at Agronomy Farm, B. A. College of Agriculture, Anand Agricultural University, Anand.

A complete set of 56 entries comprising ten parents, forty five hybrids and one standard check hybrid (GCH-7) were sown in a randomized complete block design (RBD) with three replications during *rabi* 2015-16. Each entry was grown in a single row of 6 m length keeping row to row 120 cm and plant to plant 60 cm distance. Sowing was done in the last week of August 2016-17 and all recommended agronomic practices and plant protection measures were followed for raising normal crop.

The observations were recorded on five randomly selected plants for each entries in each replication and the average value per plot was computed except days to 50 per cent flowering and days to maturity. The observations for days to 50 per cent flowering and days to maturity were recorded on plot basis.

The replication wise mean values for all the characters were subjected to analysis of variance technique suggested by Snedecor and Cochran (1967) [11] and reviewed by Panse and Sukhatme (1978) [6] to determine significant differences among genotypes.

Results and Discussion

The analysis of variance (Table 1) revealed significant differences among genotypes for all the characters except 100 seed weight, shelling out turn and oil content, which indicated the considerable amount of variability among genotypes for various characters under study. The mean squares due to genotypes were further partitioned into parents, hybrids, parents *vs* hybrids and check *vs* hybrids. The mean squares due to parents were highly significant for 9 characters out of 13 characters. This revealed the presence of variability among the parents for majority of the characters under study. The results further indicated that hybrids differed significantly for most of the characters except days to maturity, 100 seed weight, shelling out turn and oil content.

The mean squares due to parents *vs* hybrids were significant for all the characters except plant height up to primary raceme, effective length of primary raceme, 100 seed weight and shelling out turn. These indicated the differences between parents and hybrids and possibility of heterotoic effects for most of the characters. The mean squares due to check *vs* hybrids were significant for days to 50% flowering, days to maturity, plant height up to primary raceme, number of nodes up to primary raceme and effective length of primary raceme which revealed the significant difference between check and hybrids for these characters.

Seed yield is the economically important trait and breeders attempt to evolve varieties/hybrids with high seed yield. Number of hybrid combinations exhibited high magnitude of positive relative heterosis and heterobeltiosis. The estimates of heterosis revealed that 32 and 23 crosses manifested significant positive relative heterosis and heterobeltiosis for seed yield per plant, respectively, whereas, none of the cross showed significant positive standard heterosis.

The results of table 2 revealed that relative heterosis varied from -6.90per cent (ANDCI 10-6 x JI 358) to 63.58 per cent (SH1 x PCS 124) and heterobeltiosis varied from -16.85 per cent (JI 358 x JH 109) to 57.68 per cent (SH 1 x PCS 124) for seed yield per plant. The standard heterosis varied from -39.57 per cent (JI 358 x JH 109) to 12.30 per cent (SKI 324 x VH 63-1-3).

The hybrid SH 1 x PCS 124 expressed the highest relative heterosis and heterobeltiosis (63.58% and 57.68%) for seed yield per plant followed by SKI 324 x VH 63-1-3 (59.62%, and 57.49%), ANDCI 8 x SH 1 (57.47% and 48.08%) and SH 42 x PCS 124 (55.44%, and 52.83%), respectively. The results are in conformity with the findings of Kabaria and Gopani (1971) [3], Saiyed (1993) [10], Patel (1994) [8], Bhand (1996) [2], Patel (1997) [9], Knawal (2002) [4] and Patel *et al.* (2013) who also observed significant heterosis in positive direction for seed yield per plant.

The identification and utilization of most heterotic and useful crosses are very important in hybrid approach in order to make commercial cultivation of hybrid beneficial. Out of 45 hybrids tested, three promising hybrids which out yielded GCH 7 were identified in respect of seed yield per plant. They are listed in Table 3 along with, their sca effects as well as component traits showing significant desirable heterosis over better parent. The high heterotic response in these hybrids resulted due to positive heterosis for yield contributing characters like total and effective length of primary raceme, number of capsules per raceme, number of effective raceme and total seed weight of primary raceme. Therefore, heterotic effects for seed yield per plant could be a result of combinational heterosis. The best three hybrids on the basis of *per se* performance were SKI 324 x VH 63-1-3 (273.93 g), JI 358 x SKI 324 (259.27 g) and ANDCI 10-7 x SKI 324 (247.27 g).

Table 1: Analysis of variance (mean square) for various characters

Source	d.f.	Days to 50 % flowering	Days to maturity	Plant height up to primary raceme	Number of nodes up to primary raceme	Total length of primary raceme	Effective length of primary raceme	Number of capsules on primary raceme	Number of effective racemes per plant	Total seed weight of primary raceme	100 seed weight	Shelling out turn	Seed yield per plant	Oil content
Replications	2	321.03	2556.5	2471.5	2.3	54.78	40	967.53	1.76	121.7	14.9	66.97	6539.5	56.2
Genotypes	55	56.39**	145.56**	502.48**	6.13**	184.24**	196.62**	357.05**	4.21**	472.11**	8.16	62.32	3288.31**	3.10
Parents	9	23.73	166.23**	675.55**	5.59**	381.37**	364.33**	519.96**	5.77**	427.98**	2.96	33.18	1143.72	10.11**
Hybrids	44	31.74**	68.62	447.50**	4.92**	142.84**	161.95**	319.48**	3.81**	467.06**	9.53	65.31	2303.80*	1.51
Parents vs Hybrids	1	1302.72**	2485.54**	385.71	13.85**	207.68**	5.14	807.02**	11.28**	888.29**	0.76	235.54	64028.93**	12.11*
Check vs Hybrids	1	254.84**	1208.95**	1571.56*	59.72**	181.82	396.52*	62.26	0.36	578.98	1.77	12.61	3120.67	0.54
Error	110	17.29	54.34	111.18	1.28	24.18	20.01	72.44	0.89	102.25	9.61	61.09	1455.58	2.39

*, ** significant at 5 % and 1% levels, respectively.

Table 2: Best three hybrids based on heterosis over mid parent (MP), better parent (BP) and standard check (SC) for various characters

Characters		**Days to 50 per cent flowering**			**Days to maturity**		
Heterosis Over		**MP**	**BP**	**SC**	**MP**	**BP**	**SC**
1		ANDCI 8 x SH 1 (-26.18)	ANDCI 8 x SH 1 (-25.95)	ANDCI 8 x SH 1 (-29.94)	JI 358 x SH 42 (-20.52)	JI 358 x SH 42 (-16.76)	JI 358 x SH 42, JI 358 x SKI 324 (-22.03)
2		JI 358 x SH 42 (-25.45)	JI 358 x SH 42 (-24.54)	JI 358 x PCS 124 (-27.54)	JI 358 x SKI 324 (-20.00)	ANDCI 8 x SH 42 (-16.49)	ANDCI 8 x SH 42 (-21.77)
3		ANDCI 8 x JH 109 (-24.63)	ANDCI 10-6 x SH 42 (-22.16)	JI 358 x SH 42 (-26.35)	ANDCI 8 x JH 109 (-17.52)	ANDCI 8 x JH 109 (-15.63)	ANDCI 8 x JH 109 (-20.76)
Range	Min	-26.18	-25.95	-29.94	-20.52	-16.76	-22.03
	Max	0.95	5.41	-4.19	1.16	4.83	-6.33
Number of +ve significant crosses		0	0	0	0	0	0
Number of -ve significant crosses		40	32	43	27	10	45
Characters		**Plant height up to primary raceme**			**Number of nodes up to primary raceme**		
Heterosis Over		**MP**	**BP**	**SC**	**MP**	**BP**	**SC**
1		JI 358 x SKI 324 (-29.89)	JI 358 x SKI 324 (-25.41)	ANDCI 8 x PCS 124 (-49.38)	ANDCI 10-6 x JI 358 (-17.37)	ANDCI 10-6 x JI 358 (-17.05)	ANDCI 8 x PCS 124 (-35.71)
2		ANDCI 8 x SKI 324 (-26.73)	JI 358 x SH 42 (-21.10)	ANDCI 8 x SKI 324 (-44.32)	JI 358 x SKI 324 (-14.84)	JI 358 x SKI 324 (-14.34)	ANDCI 8 x SH 42 (-31.49)
3		JI 358 x SH 42 (-23.43)	JI 358 x SH 1 (-18.05)	ANDCI 8 x SH 1 (-39.71)	ANDCI 10-7 x JI 358 (-13.84)	ANDCI 10-7 x JI 358 (-13.33)	JI 358 x PCS 124 (-30.84)
Range	Min	-29.89	-25.41	-49.38	-17.37	-17.05	-35.71
	Max	22.17	38.23	5.84	6.35	18.84	-12.34
Number of +ve significant crosses		1	3	0	0	3	0
Number of -ve significant crosses		3	1	27	9	3	45

Conti…

Characters		Number of capsules on primary raceme			Number of effective racemes per plant		
Heterosis Over		MP	BP	SC	MP	BP	SC
1		ANDCI 10-6 x PCS 124 (53.20)	ANDCI 10-6 x JH 109 (34.09)	ANDCI 10-6 x SH 1 (27.21)	SH 1 x JH 109 (47.52)	JI 358 x SKI 324 (43.59), SH 1 x SKI 324 (43.59)	VH 63-1-3 x PCS 124 (34.30)
2		ANDCI 10-6 x SH 1 (44.50)	ANDCI 10-6 x PCS 124 (33.34)	SH 42 x SH 1 (22.47)	JI 358 x JH 109 (45.71)	SH 1 x JH 109 (33.33)	SH 1 x PCS 124 (29.47)
3		ANDCI 10-6 x JH 109 (41.57)	ANDCI 10-6 x SH 1 (27.90)	ANDCI 10-6 x SKI 324 (21.57)	JI 358 x SKI 324 (44.52)	JI 358 x JH 109 (32.47)	ANDCI 10-7 x PCS 124,JI 358 x VH 63-1-3 (19.81)
Range	Min	-11.88	-30.24	-34.58	-19.21	-34.40	-46.86
	Max	53.20	34.09	27.21	47.52	43.59	34.30
Number of +ve significant crosses		20	10	7	22	10	5
Number of -ve significant crosses		3	16	23	2	12	9
Characters		**Total Seed weight of primary raceme**			**100 seed weight**		
Heterosis Over		**MP**	**BP**	**SC**	**MP**	**BP**	**SC**
1		SH 1 x JH 109 (53.80)	SH 1 x JH 109 (39.49)	ANDCI 10-7 x SH 1 (22.63)	ANDCI 8 x JI 358 (13.56)	ANDCI 8 x JI 358 (12.06)	ANDCI 8 x JI 358 (11.28)
2		ANDCI 10-7 x SH 1 (46.50)	JI 358 x JH 109 (35.75)	ANDCI 10-6 x SKI 324 (15.84)	ANDCI 10-7 x JH 109 (13.15)	ANDCI 10-7 x JH 109 (11.06)	ANDCI 8 x PCS 124 (7.66)
3		SKI 324 x JH 109 (40.51)	ANDCI 10-6 x ANDCI 8 (33.06)	ANDCI 10-7 x SKI 324 (12.94)	ANDCI 10-7 x SH 1 (12.23)	ANDCI 10-7 x SH 1 (9.90)	ANDCI 10-7 x SKI 324 (6.73)
Range	Min	-35.29	-47.76	-52.97	-14.44	-17.09	-17.67
	Max	53.80	39.49	22.63	13.56	12.06	11.28
Number of +ve significant crosses		19	10	3	0	0	0
Number of -ve significant crosses		5	9	30	1	2	1

Conti…

Characters		Shelling out turn %			Seed yield per plant		
Heterosis Over		MP	BP	SC	MP	BP	SC
1		ANDCI 8 x SH 1 (19.99)	ANDCI 8 x SH 1 (17.63)	ANDCI 8 x SH 1 (9.76)	SH 1 x PCS 124 (63.58)	SH 1 x PCS 124 (57.68)	SKI 324 x VH 63-1-3 (12.30)
2		JI 358 x SKI 324 (18.07)	ANDCI 8 x SH 42 (14.46)	ANDCI 8 x SH 42 (7.12)	SKI 324 x VH 63-1-3 (59.62)	SKI 324 x VH 63-1-3 (57.49)	JI 358 x SKI 324 (6.29)
3		JI 358 x VH 63-1-3 (17.32)	ANDCI 8 x JH 109 (12.23)	ANDCI 10-7 x ANDCI 8 (7.09)	ANDCI 8 x SH 1 (57.47)	SH 42 x PCS 124 (52.83)	ANDCI 10-7 x SKI 324 (1.37)
Range	Min	-20.15	-23.50	-30.88	-6.90	-16.85	-39.57
	Max	19.99	17.63	9.76	63.58	57.68	12.30

Number of +ve significant crosses		3	0	0	32	23	0
Number of -ve significant crosses		1	1	2	0	0	17
Characters		**Oil content (%)**					
Heterosis Over		**MP**	**BP**	**SC**			
1		JI 358 x SH 1 (7.45)	JI 358 x SH 1 (6.30)	SH 42 x SKI 324 (10.02)	*Values in parenthesis indicated value of heterosis in per cent.		
2		ANDCI 10-6 x SH 1 (6.96)	ANDCI 10-6 x JI 358 (5.83)	JI 358 x SKI 324 (7.35)	MP = Mid-parent BP= Better parent SC = Standard check		
3		ANDCI 10-6 x JI 358 (6.10)	ANDCI 10-6 x SH 1 (5.54)	ANDCI 10-6 x ANDCI 10-7 (6.35)			
Range	Min	-3.06	-4.50	1.52			
	Max	7.45	6.30	10.02			
Number of +ve significant crosses		3	0	2			
Number of -ve significant crosses		0	0	0			

Table 3: Promising hybrids for seed yield per plant with heterosis over mid parent (MP), better parent (BP) and standard check (SC), their sca effects and component traits showing significant desired heterosis over mid parent, better parent and standard check

Sr. No.	**Promising hybrids**	**Heterosis (%) over**			**Seed yield per plant (g)**	**sca effects**	**Significant heterosis for component traits in desirable direction over**		
		MP	**BP**	**SC**			**MP**	**BP**	**SC**
1.	SKI 324 x VH 63-1-3	59.62**	57.49**	12.30	273.93	48.38*	DM, TL, EL, SP	--	DF, DM, NN
2.	JI 358 x SKI 324	47.65**	46.26**	6.29	259.27	42.31*	DF, DM, PH, NN, ER, SO	DF, DM, PH, NN, ER	DF, DM, PH, NN, OC
3.	ANDCI 10-7 x SKI 324	39.38**	36.71**	1.37	247.27	29.17	DM, CS, ER, SP	CS, SP	DM, NN, CS, SP

*, ** significant at 5 % and 1% levels, respectively.

DF	=	Days to 50 per cent flowering	CS	=	Number of capsules on primary raceme
DM	=	Days to maturity	ER	=	Number of effective raceme per plant
PH	=	Plant height up to primary raceme	SP	=	Total seed weight of primary raceme
NN	=	Number of nodes up to primary raceme	SO	=	Shelling out turn
TL	=	Total length of primary raceme	OC	=	Oil content
EL	=	Effective length of primary raceme			

Conclusion

Among 45 hybrids tested, none of the hybrid showed significant positive standard heterosis for seed yield per plant however, 32 and 23 crosses manifested significant positive relative heterosis and heterobeltiosis, respectively. The high heterotic response in these hybrids resulted due to positive heterosis for yield contributing characters like total and effective length of primary raceme, number of capsules per raceme, number of effective raceme and total seed weight of primary raceme. The heterotic effect for seed yield per plant could be outcome of direct effect of these attributes, and could be outcome of indirect effects of other yield contributing attributes. Therefore, heterotic effects for seed yield per plant could be a result of combinational heterosis.

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