HETEROSIS AND COMBINING ABILITY ANALYSIS FOR SEED YIELD PER PLANT AND OIL CONTENT IN CASTOR (*Ricinus communis* L.)

***JALU, R. K.; PATEL, J. B.; PITHIYA, P. H. AND CHOTALIYA, P. S.**

DEPARTMENT OF GENETICS AND PLANT BREEDING
COLLEGE OF AGRICULTURE
JUNAGADH AGRICULTURAL UNIVERSITY
JUNAGADH – 362 001, GUJARAT, INDIA

****EMAIL: rohit.jalu9@gmail.com***

ABSTRACT

An experiment was carried out to study the nature and magnitude of heterosis and combining ability for seed yield per plant and oil content in castor. The results revealed that based on per se performance of hybrids, twenty three hybrids yielded higher than GCH 7 for seed yield per plant, of which three hybrids SKP 84 × JI 435, JP 96 × JI 437 and SKP 84 × JI 437 yielded significantly higher than GCH 7. Among ten superior cross combinations for seed yield per plant, the above mentioned best per se cross combinations SKP 84 × JI 435, JP 96 × JI 437 and SKP 84 × JI 437 also had significant heterobeltiosis and standard heterosis for seed yield per plant. Two cross combinations SKP 106 x JI 434 and JP 96 x JI 431 recorded significantly the maximum and positive magnitude of standard heterosis for oil content. Among the females, SKP 106 and JP 96 and among the males, JI 441 and JI 435 were considered good general combiners, as they expressed significant and positive gca effects for seed yield per plant. Among females, JP 96 and SKP 106 and among male parents, JI 431, JI 433, JI 435 and JI 434 were the best general combiner for high oil content. The best five hybrids with respect to seed yield per plant based on significant and the maximum positive sca effects were JP 96 x JI 437, JP 104 x JI 434, SKP 84 x JI 437, SKP 84 x JI 435 and JP 104 x JI 441, while for oil content SKP 84 x JI 437, JP 96 x JI 439, SKP 84 x JI 440, SKP 106 x JI 434 and SKP 106 x JI 432 were the best five hybrids based on significant sca effects.

KEY WORDS: Castor, GCA, gene action, Heterobeltiosis, SCA, Standard heterosis

INTRODUCTION

Castor (*Ricinus communis* L., 2n = 20) is short-lived small tree or shrub with soft wood and hollow stems which can grow up to 5 m or more. Its bark is greenish to reddish brown and smooth. Leaves are palmately and deeply lobed with serrate leaf margins; long-stalked, alternate, dark green or even reddish. Its flowers are crowded on upright spikes up to 40 cm long; both sexes occur on the same plant; the upper female flowers appear before the lower male ones. Its fruits are round, deep red, prickly capsules, in dense clusters; containing three tick-like, brown or reddish-brown marbled, very poisonous seeds with high oil content is generally grown for seeds. Castor seed oil is being used widely for various purposes. It is used as a lubricant in high-speed engines and aeroplanes, in the manufacture of soaps, transparent paper, printing-inks, varnishes, linoleum and plasticizers. It is also used for medicinal and lighting purposes. The cake is used as manure and plant stalks as fuel or as thatching material or for preparing paper-pulp. In the silk-producing areas, leaves are fed to the silkworms (Weiss, 2000).

The phenomenon of heterosis has proved to be the most important genetic tool in enhancing the yield of self as well as cross pollinated species in general and castor in particular. With the availability of cent per cent pistillate lines in castor, exploitation of heterosis or hybrid vigour on commercial scale has become commercially feasible and economical (Gopani *et al.*, 1968). In Gujarat, real breakthrough in castor production has come with the development and release of hybrids for commercial cultivation. Still, there is potential to further increase in yield level of castor through genetic improvement.

In genetic improvement, the choice of appropriate parents to be incorporated in hybridization programme is very crucial step for breeders, particularly if the aim is improvement of seed yield. For this, it is always essential to evaluate available promising lines in their hybrid combinations for yield (Giriraj *et al.*, 1973). The use of parents of known superior genetic worth ensures much better success. Some idea may be obtained from their *per se* performance. However, proper information on magnitude of heterosis, combining ability and gene action for seed yield per plant and another important character oil content involved in the inheritance of different parents and their crosses would be more helpful to plant breeders in selecting the elite parents and desirable cross combinations for commercial exploitation of hybrid vigour and also in formulating the efficient breeding programme for the improvement of seed yield and oil content (Dangaria *et al.*, 1987).

The present investigation was, therefore, planned in castor to study heterosis, combining ability and gene action by using line x tester analysis involving four pistillate lines (female parents) and 10 male lines (male parents).

MATERIALS AND METHODS

Experimental material consisting of 55 entries comprised of four pistillate lines (JP 96, JP 104, SKP 84 and SKP 106, used as testers/females) and ten inbred lines (JI 431, JI 432, JI 433, JI 434, JI 435, JI 437, JI 438, JI 439, JI 440 and JI 441, used as lines/males) and their 40 hybrids developed through line x tester mating design along with standard check hybrid (GCH 7) were evaluated in a randomized block design with three replications. The materials were evaluated during *kharif-rabi* 2016-17 at the Sagdividi Farm, Department of Seed Science and Technology, College of Agriculture, Junagadh Agricultural University, Junagadh. Five competitive plants per each entry in each replication were randomly selected before flowering and tagged for the purpose of recording the seed yield per plant (g) and oil content (%). The analysis of variance for experimental design was performed to test the significance of difference among the genotypes for both the traits as per the method suggested by Panse and Sukhatme (1985). Heterobeltiosis was estimated as per the procedure given by Fonseca and Patterson (1968) using mean values for seed yield per plant and oil content over replications. Standard heterosis referred as the superiority of F_1 over standard hybrid GCH 7 and it was estimated as per the formula given by Meredith and Bridge (1972).

RESULTS AND DISCUSSION

The analysis of variance was performed to test the significant differences among genotypes, parents, hybrids and parents *vs*. hybrids for seed yield per plant and oil content and are presented in Table 1. The results revealed that mean squares due to genotypes were highly significant for both the characters. The mean squares due to genotypes were further partitioned into mean squares due to parents, hybrids and parents *vs*. hybrids. The analysis of variance revealed that mean squares due to hybrids and parents *vs*. hybrids were highly significant for both the characters, but mean squares due to parents were non-significant. This indicated the existence of considerable genetic variability among the hybrids for both the characters. The results are in accordance to those reported by Ramana *et al.* (2005) and Sapovadiya *et al.* (2015) in castor.

Considering *per se* performance of hybrids, twenty three hybrids yielded higher than GCH 7 for seed yield per plant, of which three hybrids SKP 84 × JI 435 (324.58 g), JP 96 × JI 437 (322.28 g) and SKP 84 × JI 437 (313.41 g) yielded significantly higher than GCH 7 (280.80 g). Among the ten superior cross combinations for seed yield per plant, the above mentioned cross combinations SKP 84 × JI 435, JP 96 × JI 437 and SKP 84 × JI 437 also had significant heterobeltiosis and standard heterosis for seed yield per plant (Table 4).

With respect to the performance of hybrids for seed yield per plant, it was observed that thirty four hybrids over better parent and three hybrids over standard check (GCH 7) exhibited significant and positive heterosis (Table 4).The cross SKP 84 × JI 435 depicted significantly the highest and positive heterobeltiosis (39.95 %), standard heterosis (15.59 %) as well as the highest seed yield per plant (324.58 g). JP 96 × JI 437 and SKP 84 × JI 437 were the next two best crosses exhibited significant and positive heterobeltiosis (29.29 % and 35.13 %, respectively), standard heterosis (14.77 % and 11.61 %, respectively) and *per se* performance (322.28 g and 313.41 g, respectively). In such cases, expression of heterotic response over better and standard parents indicated the real superiority of hybrids from the commercial point of view. High heterosis for seed yield in castor has also been reported by several workers (Manivel *et al.*, 1999; Lavanya and Chandramohan, 2003; Golakia *et al.*, 2004; Thakkar *et al.*, 2005; Patel and Pathak, 2006; Sridhar *et al.*, 2009; Barad *et al.*, 2009; Chaudhari *et al.*, 2011; Chaudhari and Patel, 2014; Makani *et al.*, 2015; Sapovadiya *et al.*, 2015; and Patted *et al.*, 2016).

The heterobeltiosis and standard heterosis for oil content ranged from -3.08 per cent (SKP 84 × JI 432) to 9.56 per cent (SKP 106 × JI 434) and -4.30 per cent (SKP 106 × JI 437) to 7.07 per cent (SKP 106 × JI 434), respectively (Table 4). Out of 40 crosses, six and two cross combinations manifested significant and positive heterobeltiosis and standard heterosis, respectively. The cross combination SKP 106 x JI 434 recorded significantly the highest and desirable magnitude of heterobeltiosis (9.56 %) followed by SKP 106 x JI 435 (7.46 %), SKP 106 x JI 431 (7.41 %), SKP 84 x JI 440 (7.39 %) and SKP 106 x JI 433 (7.02 %) for oil content. Two cross combinations SKP 106 x JI 434 (7.07 %) and JP 96 x JI 431 (6.96 %) recorded significantly the maximum and positive magnitude of standard heterosis for oil content. SKP 106 x JI 434 recorded significantly the highest and positive heterobeltiosis (9.56 %) and standard heterosis (7.07 %). Significant estimates of heterosis have been reported by Lavanya and Chandramohan (2003) and Patel *et al.* (2013) for oil content.

The analysis of variance for combining ability revealed that general combining ability and specific combining ability variance were significant for both the characters, which indicated that both additive and non additive gene actions were important in the inheritance of these traits

(Table 2). The ratio of σ^2gca/σ^2sca was less than unity for seed yield per plant and oil content.

Among the females, SKP 106 (52.26) and JP 96 (43.66) and among the males, JI 441 (30.30) and JI 435 (28.39) were considered good general combiners, as they expressed significant and positive gca effects for seed yield per plant (Table 3). Female parent JP 104 (-12.21) and male parents JI 440 (-33.22) and JI 434 (-21.17) were rated as poor general combiners for seed yield per plant, as they depicted significant and negative gca effects. Out of 14 parents, 11 parents exhibited significant gca effects for oil content, of which six parents had positive gca effects and rest five depicted negative gca effects (Table 3). Among females, JP 96 (2.73) and SKP 106 (1.04) were good general combiners, while SKP 84 (-2.59) and JP 104 (-2.03) were poor general combiners for oil content. In case of male parents, JI 431 (3.59) was the best general combiner for high oil content followed by JI 433 (3.20), JI 435 (2.75) and JI 434 (1.55), while JI 439 (-3.12), JI 438 (-2.60) and JI 432 (-2.15) were poor general combiners for oil content.

Out of 40 hybrids, eleven cross combinations depicted significant and positive sca effects, while nine cross combinations exhibited significant and negative sca effects for seed yield per plant (Table 4). The sca effects for seed yield per plant varied from -43.81 (SKP 106 x JI 437) to 31.28 (JP 96 x JI 437). The best five hybrids with respect to seed yield per plant based on significant and the maximum positive sca effects were JP 96 x JI 437 (31.28), JP 104 x JI 434 (29.58), SKP 84 x JI 437 (25.75), SKP 84 x JI 435 (24.61) and JP 104 x JI 441 (20.28). The sca effects for oil content ranged from -2.52 (SKP 106 x JI 437) to 1.97 (SKP 84 x JI 437). Ten cross combinations displayed significant and positive sca effects, of which five cross combinations noted significant and positive sca effects, while five cross combinations expressed significant and negative sca effects (Table 4). The best five hybrids with respect to oil content based on significant and the maximum positive sca effects were SKP 84 x JI 437 (1.97), JP 96 x JI 439 (1.90), SKP 84 x JI 440 (1.81), SKP 106 x JI 434 (1.64) and SKP 106 x JI 432 (1.50).

The estimates of sca effects revealed (Table 4) that none of the crosses was consistently superior for seed yield per plant and oil content. Out of 40 hybrids studied, 11 cross combinations exhibited significant and positive sca effects for seed yield per plant. The highest yielding hybrid SKP 84 × JI 435 had also registered positive sca effect for seed yield per plant involved average x good general combiner parents for seed yield per plant. The sca effect in this cross combination was also accompanied by significant and high heterobeltiosis as well as standard heterosis (Table 5). The third high yielding cross, SKP 84 × JI 437 involved average x average poor combiners for seed yield per plant, also exhibited significant and desirable sca effects for oil content.

CONCLUSION

From the results and discussion, it can be concluded that considerable heterobeltiosis and standard heterosis observed for seed yield and oil content that suggested the presence of large genetic diversity among the parents and also unidirectional distribution of allelic constitution contributing towards desirable heterosis in the present material. Three crosses *viz*., SKP 84 x JI 435, JP 96 x JI 437 and SKP 84 x JI 437 appeared to be the most suitable crosses for exploitation in practical plant breeding programme in castor, as they recorded 39.95 per cent, 29.29 per cent and 35.13 per cent significantly the higher heterosis over their respective better parent; and 15.59 per cent (324.58 g), 14.77 per cent

(322.28 g) and 11.61 per cent (313.41 g) significantly the higher heterosis over standard check GCH 7 (280.80 g). Best two crosses SKP 106 x JI 434 (7.07 %) and JP 96 x JI 431 (6.96 %), which exhibited significant standard heterosis for oil content can be use in further breeding programme to improve oil content in castor.

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Table 1: Analysis of variance for experimental design (mean squares) for different characters in castor

Sources of Variation	d.f.	Seed Yield Per Plant (g)	Oil Content (%)
Replications	2	5372.66**	1.96
Genotypes	53	3326.31**	7.10**
Parents (P)	13	570.79	3.05
Hybrids (H)	39	1322.99**	5.54**
Parents *vs*. Hybrids	1	117289.24**	120.54**
Error	106	316.89	2.15

***** Significant at 1 per cent levels of significance***

Table 2: Analysis of variance and variance components of combining ability and per cent contribution for seed yield per plant and oil content in castor

Sources of Variation	d.f.	Seed Yield Per Plant (g)	Oil Content (%)
Females	3	2160.20	9.35
Males	9	2450.64*	5.92
Females *x* males	27	853.19**	5.00*
Error	78	328.91	2.67
σ^2**GCA**		94.31** (10)	0.23 (7)
σ^2**SCA**		174.76**	0.77
σ^2**GCA/**σ^2**SCA**		0.54	0.30

****, ** Significant at 5 per cent and 1 per cent levels of significance, respectively***

Table 3: Estimates of general combining ability (gca) effects for Seed yield per plant and oil content in castor

Parents	Seed Yield Per Plant (g)	Oil Content (%)
JP 96	43.66**	2.73**
JP 104	-12.21*	-2.03**
SKP 84	1.75	-2.59**
SKP 106	52.26**	1.04*
SE(g_i)	5.38	0.52
JI 431	13.22	3.59**
JI 432	12.34	-2.15**
JI 433	5.86	3.20**
JI 434	-21.17**	1.55*
JI 435	28.39**	2.75**
JI 437	9.08	1.18
JI 438	5.17	-2.60**
JI 439	-11.65	-3.12**
JI 440	-33.22**	1.28
JI 441	30.30**	1.38
SE(g_j)	7.14	0.76

****, ** Significant at 5 per cent and 1 per cent levels of significance, respectively***

Table 4: Per cent heterosis over better parent (H_1) and standard check (H_2) and Specific combining ability for seed yield per plant and oil content in castor

Hybrids	Heterosis				Specific Combining Ability	
	Seed Yield Per Plant (g)		Oil Content (%)		Seed Yield Per Plant (g)	Oil Content (%)
	H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)		
JP 96 × JI 431	14.84 *	1.94	4.59	6.96 *	-8.87	0.84
JP 96 × JI 432	11.65	-0.89	-0.21	0.14	-15.95*	-0.77
JP 96 × JI 433	14.59 *	1.72	0.39	0.75	-11.14	-0.83
JP 96 × JI 434	7.93	-4.19	1.24	1.59	-13.69*	-0.76
JP 96 × JI 435	21.90 **	8.21	3.04	3.41	-6.44	-0.08
JP 96 × JI 437	29.29 **	14.77 **	1.87	2.23	31.28**	-0.00
JP 96 × JI 438	17.85 **	4.62	0.45	0.81	8.68	0.73
JP 96 × JI 439	11.31	-1.19	3.26	3.62	-8.45	1.90**
JP 96 × JI 440	7.17	-4.86	1.47	1.82	17.46*	-0.32
JP 96 × JI 441	18.48 **	5.18	0.62	0.98	-10.86	-0.69
JP 104 × JI 431	17.08 **	-4.12	4.39	2.16	-10.00	0.39
JP 104 × JI 432	32.06 **	3.34	0.53	0.47	19.81**	0.31
JP 104 × JI 433	26.18 **	-1.27	2.72	0.54	7.35	-0.01
JP 104 × JI 434	30.15 **	3.43	-0.12	-2.25	29.58**	-1.73**
JP 104 × JI 435	27.92 **	0.09	3.25	1.05	-13.35*	-0.31
JP 104 × JI 437	21.10 **	-3.18	4.34	2.12	-11.22	0.85
JP 104 × JI 438	14.99 *	-5.59	-1.08	-3.19	-12.08	-0.30
JP 104 × JI 439	16.61 *	-7.24	-1.71	-3.81	-9.54	-0.81
JP 104 × JI 440	-3.53	-24.51 **	3.81	1.59	-29.83**	0.48
JP 104 × JI 441	29.20 **	7.77	5.10	2.86	20.28**	1.15
SKP 84 × JI 431	28.61 **	6.22	0.49	-3.17	14.48*	-1.82**
SKP 84 × JI 432	15.98 *	-4.21	-3.08	-3.13	-12.92*	-1.04
SKP 84 × JI 433	22.41 **	1.11	3.29	-0.47	-7.52	-0.09
SKP 84 × JI 434	13.53 *	-6.23	6.04 *	2.18	-18.08**	0.85
SKP 84 × JI 435	39.95 **	15.59 **	4.56	0.75	24.61**	-0.04
SKP 84 × JI 437	35.13 **	11.61 *	5.48	2.94	25.75**	1.97**
SKP 84 × JI 438	19.14 **	-1.60	0.57	-3.09	-14.43*	0.15
SKP 84 × JI 439	22.15 **	0.89	-0.33	-3.47	7.74	-0.24
SKP 84 × JI 440	9.73	-9.37	7.39 *	3.47	6.14	1.81**
SKP 84 × JI 441	23.42 **	2.95	-0.73	-2.85	-14.78*	-1.24*
SKP 106 × JI 431	28.75 **	5.44	7.41 *	3.02	5.38	0.58
SKP 106 × JI 432	37.88 **	10.00	3.41	3.36	16.06*	1.50*
SKP 106 × JI 433	32.87 **	6.00	7.02 *	2.98	8.31	0.95
SKP 106 × JI 434	23.87 **	-1.18	9.56 **	7.07 *	-9.81	1.64*
SKP 106 × JI 435	34.39 **	7.21	7.46 *	3.06	-10.82	0.44
SKP 106 × JI 437	14.80 *	-8.21	-1.94	-4.30	-43.81**	-2.52**
SKP 106 × JI 438	32.93 **	9.15	0.84	-3.28	17.94**	-0.58
SKP 106 × JI 439	30.23 **	3.89	-0.27	-3.41	12.25	-0.84
SKP 106 × JI 440	20.74 **	-3.68	1.21	-2.93	15.22*	-1.96**
SKP 106 × JI 441	31.13 **	9.38	4.83	2.60	9.36	0.79
Mean Heterosis	22.11	1.22	2.52	0.62	-	-
S.Em ±	14.80		1.33		-	-
SE(s_{ij})	-		-		6.47	0.61

, ** Significant at 5 per cent and 1 per cent levels of significance, respectively

Table 5: Summary of three best *per se* performing parents and good general combiners along with three best hybrids based on *per se* performance and significant heterobeltiosis, standard heterosis and SCA effects for seed yield per plant and oil content in castor

Sr. No.	Characters	Rank	Parents		Crosses			
			***Per se* Performance**	**GCA Effects**	***Per se* Performance**	**Heterobeltiosis**	**Standard Heterosis**	**SCA Effects**
1	**Seed yield per plant (g)**	**I**	JP 96	SKP 106	SKP 84 × JI 435	SKP 84 × JI 435	SKP 84 × JI 435	JP 96 × JI 437
		II	JI 441	JP 96	JP 96 × JI 437	SKP 106 × JI 432	JP 96 x JI 437	JP 104 × JI 434
		III	SKP 84	JI 441	SKP 84 × JI 437	SKP 84 × JI 437	SKP 84 × JI 437	SKP 84 × JI 437
2	**Oil content (%)**	**I**	JP 96	JI 431	SKP 106 × JI 434	SKP 106 × JI 434	SKP 106 × JI 434	SKP 84 × JI 437
		II	JI 432	JI 433	JP 96 × JI 431	SKP 106 × JI 435	JP 96 × JI 431	JP 96 × JI 439
		III	JI 441	JI 435	JP 96 × JI 439	SKP 106 × JI 431	-	SKP 84 x JI 440

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