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Studies on combining ability and heterosis for seed yield and yield components in *Rabi* castor (*Ricinus communis* L.)

Dushyant Dube, Ronak Bhakta, Kanak Bhati and Vaibhav Lodhum

Abstract
Eleven castor (*Ricinus communis* L.) genotypes consisting of four lines and seven testers and crossed in a line × tester mating design. The ratio of GCA and SCA variance showed non- additive gene action was per-dominant controlling all the traits except for oil content. None of the parents and hybrid found good general and specific combiner for all the characters, respectively. Parental lines GP-525, GP-532 and SKP-84 were good general combiners for seed yield per plot and for one or more characters. While SKP-84 × GP-664, ANDCP-8-1 × GP-525 and SKP-84 × GP-532 were the best specific combiner for seed yield per plot. The higher economic heterosis for seed yield per plot was exhibited by the hybrid ANDCP 8-1 × GP-525 (24.0%) followed by SKP-84 × GP-525 (21.9%), SKP-84 × GP-532 (19.2%) and SKP-84 × GP-664 (16.3%). The *per se* performance of parents and hybrids were not always reflected in high GCA and SCA effects.

Keywords: *Rabi* Castor, GCA and SCA effects, combining ability, Heterobeltiosis, Yield & Yield components

1. Introduction
Castor (*Ricinus communis* L., 2n=20) is an industrially important non-edible oil seed crop widely cultivated in the arid and semi-arid regions of the world. Castor is sexually polymorphic species with different sex forms *viz.*, monoecious, pistillate, hermaphrodite and pistillate with interspersed staminate flowers (ISF). Among those; India, Brazil, China, Russia, Thailand and Philippines are the principle castor growing countries. India contributes 65 per cent of the world castor oil demands. India is world leader in area, production and productivity with 11.20 lakh ha, 16.30 lakh tones and 1455 kg/ha, respectively during the year 2016-17 (FAOSTAT, 2016) [7].
Combining ability is a powerful tool to select good combiners and thus selecting the appropriate parental lines for hybridization programme. In addition, the information on nature of gene action will be helpful to develop efficient crop improvement programme. General combining ability is due to additive and additive x additive gene action and is fixable in nature while specific combining ability is due to non-additive gene action which may be due to dominance or epistasis or both and is non-fixable. The presence of non-additive genetic variance is the primary justification for initiating the hybrid breeding programme (Cockerham, 1961) [5].
Heterosis breeding is an important crop improvement method adopted in many crops all over the world. It is a quick and convenient way of combining desirable characters which has assumed greater significance in the production of F_1 hybrids. The superiority of hybrids depends on their yield potential over the better released varieties and the extent of heterosis for seed yield. The aim of heterosis analysis is to find out the best combination of crosses giving high degree of useful heterosis and characterization of hybrids for commercial exploitation.

Materials and Methods
The experimental material comprising of four lines (SKP-84, VP 1, ANDCP8-1, Geeta,) and seven testers (GP-525, GP-532, GP-664, DCS-84, DCS-9, RG- 631, and RG-3041) were selected on the basis of the morphological differences. All these eleven parents were crossed to produce 28 F_1 hybrids according to line × tester analysis mating design developed by Kempthorne (1957) [12]. The resulting 28 hybrids along with 11 parents and one standard check was included in crosses were grown in a randomized block design replicated thrice at the NAU

campus farm, Navsari Agricultural University, Navsari-396450, Gujarat during *rabi* 2014-15. Each entry planted in a 6 meter long row with inter and intra row spacing of 120 × 60 cm. All the recommended agronomic and plant protection practices were uniformly applied throughout the crop growth period to raise a good crop.

The observation were recorded on five randomly selected plants for 11 characters in each replication for each genotype and the average value per plant was computed except for days to 50 percent flowering and days to 50 percent maturity of primary spike. The observations of both these characters were recorded on population basis.

Data recorded were subjected to analysis of variance according to Panse and Sukhatme (1978) [14] to determine significant differences among genotypes. Combining ability effects are very effective genetic parameter in deciding the next phase of breeding programs. They were computed according to the line × tester method.

Result and Discussion

ANOVA conforms that mean square value due to genotypes were highly significant for all the characters, that mean presence of sufficient amount of genetic variability in experimental material for the characters under study (Table-1). ANOVA also revealed that existence of variability among parents and hybrids for all the characters. The comparison between parents *vs*. hybrids indicated that parents and hybrids differed significantly for all the characters except for number of capsules on primary spikes and consequently the evidence for the possibility of existence of heterotic effects for these traits. The results are in accordance to those reported by Ramana *et al.* (2005) [23] and Sapovadiya *et al*. (2015) [25] in castor.

Mean sum of squares due to tester for effective primary spike length, number of capsules per primary spike and line was significant for days to 50% flowering, number of nodes up to primary spike and 100 seed weight. Whereas, testers *vs*. lines were found significant for majority of traits except for seed yield per plot and oil content (Table-2). The variance components due to male were higher than those in females for plant height up to primary spike, effective primary spike length, number of capsule per primary spike and seed yield per plot. While, females contributed largely in comparison to males for total genetic variance days to flowering, days to maturity, number of nodes up to primary spike, effective spikes per plant, 100 seed weight, volume weight and oil content. Both additive and non-additive genetic variances were important for all the characters. However, estimates of SCA variance were considerably higher than those of GCA variance for all the characters except for oil content. The results were confirmation with the findings of Lavanya and Chandramohan (2003) [13], Patel *et al*. (2015) [20] and Punewar *et al*. (2017) [21]. Looking to the significance of both types of gene actions in the expression of different traits, it is suggested that bi-parental mating with reciprocal recurrent selection should be employed so that additive as well as non-additive gene action could be exploited simultaneously for population improvement. However, in view of the preponderance of non-additive gene action and high heterosis observed for seed yield and yield attributing traits, it is suggested that heterosis breeding can profitably be used for exploitation of hybrid vigour in castor on commercial scale.

The estimates of GCA effects revealed that none of the parent was found good general combiner for the studied traits. This finding akin with the results of Choudhary and Patel (2014) [3] and Jalu *et al*. (2017) [10]. So, it was difficult to pick good combiners for all the characters together because the combining ability effects were not consistent for all the yield components, possibly because of negative association among of the characters (Patel and Nakarani, 2016) [17]. This shows that genes for different desirable characters would have to be combined from different sources. Pistillate SKP 84 was good general combiner for number of nodes to primary spike, effective primary spike length, number of capsules on primary spike, effective spikes per plant and seed yield per plot. Parental lines VP-1 and ANDCP-8-1 were found good general combiners earliness (days to 50% flowering and days to maturity) and dwarfness (number of nodes to primary spike and plant height) while Geeta for effective spikes per plant. Among tester parents GP 525 and GP 532 were good general combining ability for seed yield per plot; number of nodes to primary spike and for atleast two important yield attributes *viz*., effective spikes length and number of capsules per primary spike. The male parent GP 664 was good general combiner for number of capsule on primary spike and DCS 84 for effective primary spike length. Patel (2010) [15] and Kasture *et al*. (2014) reported SPK-84 was good general combiners for seed yield and one or more of its related yield contributing traits.

The estimates of specific combining ability effect provide information on role of intra and interallelic interactions in the expression of heterotic effects and inheritance of a character. The perusal of data on SCA effects (Table 4) revealed that none of the hybrid was consistently superior for all the traits. This result also reported by Punewar *et al.* (2017) [21] and Jalu *et al*. (2017) [10]. Out of 28 hybrids studied, 15 cross combinations exhibited positive SCA effects for seed yield per plot. Only three hybrids on the basis of significant positive SCA effects for seed yield per plot were SKP-84 × GP-664, ANDCP-8-1 × GP-525 and SKP-84 × GP-532. These hybrids also exhibited significant positive SCA effects for majority of yield attributing traits *viz*., effective primary spike length, number of capsules on primary spike and number of effective branches per plant. These findings also confirmed by Kasture *et al*. (2014) [11], Patel *et al*. 2017 [4] and Jalu *et al*. (2017) [10]. Above hybrids with significant SCA effects involved the hybrids having high × high or high × average general combiner for seed yield per plot indicating the significance of both additive and non-additive gene action in governing the traits. The involvement of at least one good general combiner was also reported by several researchers by Golakia *et al*., (2008) [8]; Lavanya and Chandramohan (2003) [13]; Barad *et al*., (2009) [2] and Ramesh *et al*. (2013) [24].

Enhancement in yield is the most central objectives, so the superiority of hybrids over best cultivated hybrid is essential for increasing its commercial value. Castor is highly cross pollinated crop and with the availability of 100 per cent pistillate lines, heterosis has been successfully exploited in castor. So, the examination of performance of hybrids in respect of heterosis over better parent and standard heterosis (GCH-7) in 28 hybrids for all eleven traits. The higher economic heterosis for seed yield per plot was exhibited by the hybrid ANDCP 8-1 × GP-525 (24.0%) followed by SKP-84 × GP-525 (21.9%), SKP-84 × GP-532 (19.2%) and SKP-84 × GP-664 (16.3%) are presented in Table 5. Among above crosses, ANDCP 8-1 × GP-525 also exhibited desired economic heterosis for days to 50% flowering, days to maturity, effective primary spike length, number of capsules on primary spike, effective spikes per plant, 100 seed weight and volume weight. Similarly hybrid SKP-84 × GP-525 also exhibited desirable standard heterosis for days to 50% flowering, number of nodes to primary spike, plant height, effective primary spike length, number of capsules on primary spike, effective spikes per plant and 100 seed weight; hybrid SKP-84 × GP-532 for days to maturity, plant height, effective primary spike length, number of capsules on primary spike, effective spikes per plant and 100 seed weight; cross SKP-84 × GP-664 for plant height, effective primary spike length, number of capsule on primary spike, effective spikes per plant and 100 seed weight. Similar result was reported by Patel (2010) [15], Patel and Chauhan (2013) [19], Ramesh *et al.* (2013) [24], Patel *et al.* (2014) [3] and Chaudhari and Patel (2014) [3]. This emphasized that high degree of heterosis for seed yield might be attributed to the heterosis for these component traits. Graffius (1956) [9] have suggested that there cannot be any gene system for seed yield *per se*, as yield is an end product of the multiplicative action and interaction of several yield components. Similar findings have been reported by Purohit *et al.* (2010) [22] and Punewar *et al.* (2017) [21]. Further, it is also seen that effective primary spike length, number of capsules on primary spike, effective spikes per plant were the major key components for increasing the seed yield per plot in hybrids. Such associations of seed yield with yield components more or less were observed by Patel and Chauhan (2013), Jalu *et al.* (2017) [10], Punewar *et al.* (2017) [21], Chaudhari *et al.* (2017).

Table1: Analysis of variance for various characters in castor

Sources of variation	d.f.	DF	DM	ND	PH	LS	CS	ES	SW	VW	SY	OC
Replications	2	138.8	296.3	1.2	38.8	109.4	2.76	0.23	2.5	6.9	0.01	0.4
Genotypes	39	328.4**	541.2**	27.6**	1021.7**	459.1**	835.6**	17.8**	12.8**	44.0**	0.19**	19.3**
Parents	10	116.2	107.9	17.5**	1233.3**	246.9**	579.7**	11.1**	14.6**	89.7**	0.08**	59.5**
Lines	3	30.7	86.5	28.2**	3392.3**	138.9*	761.2**	24.2**	1.4	6.5	0.01	163.2**
Testers	6	150.0*	63.8	6.0**	69.5	280.9**	455.3**	2.0*	18.5**	76.8**	0.11**	7.3
(F Vs M)	1	169.7	436.4	54.5**	1739.0**	367.1**	781.4**	26.3**	30.6*	416.4**	0.07	61.7**
P Vs H	1	534.6**	612.5*	212.7**	5800.6**	363.5**	38.9	100.8**	60.0**	426.1**	0.10*	60.9**
Hybrids (H)	27	399.3	699.0**	24.5**	766.4**	541.2	959.8**	17.2**	10.4**	13.0**	0.24**	2.9
Error	76	65.3	127.6	1.2	77.8	44.6	36.9	0.8	5.2	2.5	0.02	4.5

*, ** Significant at 5% and 1% levels of probability, respectively

DF- Days to 50% flowering	ES- Effective spikes per plant
DM- Days to maturity	SW- 100 Seed weight (g)
ND-Number of nodes to primary spike	VW- Volume weight (g/100ml)
PH- Plant height (cm)	SY- Seed yield (kg/plot)
LS- Effective length of primary spike (cm)	OC- Oil content (%)
CS- Number of capsules on primary spike	

Table 2: Mean square due to General & Specific Combining ability

Source	df	DF	DM	ND	PH	LS	CS	ES	SW	VW	SY	OC
Replication	2	214.6*	229.8	1.0	4.9	118.0	11.0	0.3	0.51	5.38	0.01	2.60
Hybrids	27	399.3**	699.0**	24.5**	766.4**	541.2**	959.8**	17.2**	10.4**	12.96**	0.24	2.92
Line effect	3	1002.3*	421.3	58.1*	744.1	954.9	1534.1	39.5	27.8*	9.39	0.48	5.17
Tester effect	6	469.0	464.6	29.8	866.0	1020.0*	1721.2*	11.8	9.0	9.53	0.54	3.46
Female× males	18	275.6**	823.5**	17.1**	736.9**	312.6**	610.3**	15.3**	7.9**	14.70**	0.10	2.37
Errors	54	64.5	155.9	1.3	84.7	52.9	41.2	1.0	3.0	2.74	0.02	3.12
						Estimates						
σ^2**f**		34.6	-19.2	1.9	0.3	30.6	44.0	1.2	0.95	-0.25	0.018*	0.13
σ^2**m**		16.1	-29.9	1.1	10.8	59.0	92.6	-0.3	0.09	-0.43	0.036**	0.09
σ^2**gca**		2.7	-2.8	0.2	0.7	5.1	7.8	0.04	0.05	-0.03	0.024**	0.01
σ^2**sca**		70.1	231.9	5.3	219.7	89.3	191.2	4.8	0.91	4.06	0.02	-0.70
σ^2**gca/**σ^2**sca**		0.04	0.011	0.030	0.002	0.056	0.040	0.008	0.054	-0.007	0.001	-0.010

*, ** Significant at 5% and 1% levels of probability, respectively

Table 3: Estimates of general combining ability effects of parents for various characters in castor

Parents	DF	DM	ND	PH	LS	CS	ES	SW	VW	SY	OC
SKP-84	1.39	2.07	1.95**	3.83	6.33**	12.96**	0.78**	0.69	-0.24	0.154**	0.693
VP-1	-9.89**	-6.02*	-0.49	-1.66	2.31	-5.61**	-1.04**	-1.64**	0.97**	-0.208**	0.088
ANDCP-8-1	2.34	-0.45	-1.05**	-7.65**	0.83	-4.40**	-1.26**	0.89	-0.17	0.006	0.117
Geeta	6.15**	4.40	0.76**	5.49**	-9.49**	-2.67*	1.52**	0.05	-0.55	0.049	0.488
S. E. (Lines)	2.46	1.76	0.23	1.92	1.45	1.32	0.19	0.49	0.34	0.03	0.46
CD at 5%	4.94	3.53	0.47	3.85	2.92	2.65	0.40	0.99	0.69	0.06	0.92
GP-525	-9.33**	-4.64	-1.56**	4.59	8.91**	17.06**	1.31**	0.25	1.09*	0.369**	-0.179
GP-532	0.33	1.52	-0.76*	-12.46**	5.37**	12.59**	1.35**	0.95	-1.69**	0.169**	-0.979
GP-664	1.33	-4.72	1.08**	3.68	-2.57	4.61*	0.41	0.58	-0.10	0.077	0.271
DCS-84	11.25**	1.85	0.77*	13.48**	12.96**	-4.66*	0.38	-1.08	0.60	-0.089	-0.070
DCS-9	-3.91	-7.64	-1.65**	-4.31	-4.50*	-2.93	-1.88**	-0.3	0.50	-0.206**	-0.054

RG-631	1.50	2.85	-0.53	-6.36	-11.35**	-12.05**	-0.33	0.79	-0.23	-0.181**	0.780
RG-3041	-1.16	10.77	2.65**	1.38	-8.82**	-14.61**	-0.24	-1.11	-0.17	-0.139**	0.230
S. E. (Testers)	3.26	2.33	0.31	2.54	1.92	1.75	0.26	0.65	0.45	0.04	0.61
CD at 5%	6.53	4.67	0.63	5.10	3.86	3.51	0.52	1.31	0.91	0.08	1.22

*, ** Significant at 5% and 1% levels of probability, respectively

Table 4: Estimates of specific combining ability effects of parents for various characters in castor

Parents	DF	DM	ND	PH	LS	CS	ES	SW	VW	SY	OC
SKP-84 x GP-525	-4.1	3.6	-3.45**	-15.7**	-1.1	-12.4**	0.1	-0.0	1.43	0.05	-0.507
SKP-84 x GP-532	-7.1	-25.9**	0.27	6.5	12.4**	8.4*	0.4	0.1	-1.34	0.18*	0.626
SKP-84 x GP-664	8.9	9.3	-1.03	-13.7**	12.1**	11.8**	3.1**	2.8*	0.26	0.24**	0.110
SKP-84 x DCS-84	23.6**	5.8	4.53**	28.9**	-5.9	-1.6	0.2	-0.1	1.42	-0.15	-0.382
SKP-84 x DCS-9	-0.9	11.6	-2.23**	-11.1*	5.6	10.8**	-2.2**	0.0	2.15*	-0.10	0.501
SKP-84 x RG-631	-11.6*	1.1	-1.01	-7.3	-7.2	1.6	-3.9**	-0.9	-0.63	-0.09	0.501
SKP-84 x RG-3041	-8.6	-5.5	2.92**	12.4*	-16.0**	-18.6**	2.3**	-1.9	-3.29**	-0.13	-0.849
VP-1 x GP-525	9.1	18.0**	-0.70	11.9*	-9.4*	-18.4**	-0.5	0.3	-1.04	-0.15	0.379
VP-1 x GP-532	0.5	6.2	-0.57	10.1	3.3	-5.5	1.3*	1.2	-1.06	0.11	-2.188
VP-1 x GP-664	-5.5	-30.2**	2.21**	10.1	-1.4	-10.0**	-2.1**	-2.8*	1.44	0.01	1.229
VP-1 x DCS-84	-3.4	-16.8*	-0.97	-20.4**	-6.1	6.7	-1.6**	-1.7	1.47	0.17	0.504
VP-1 x DCS-9	0.7	16.4*	3.35**	-9.3	1.3	4.3	0.6	1.3	-2.59**	-0.14	-0.080
VP-1 x RG-631	-1.7	6.5	-0.99	1.7	3.5	-2.7	3.4**	1.9	0.57	-0.07	-0.713
VP-1 x RG-3041	0.3	-0.1	-2.32**	-4.1	8.7*	25.6**	-1.0	-0.2	1.21	0.06	0.870
ANDCP-8-1 x GP-525	0.6	-3.9	4.02**	20.9**	13.4**	19.7**	1.5**	-0.1	2.70**	0.20*	-0.383
ANDCP-8-1 x GP-532	9.9*	12.6	-0.10	0.3	-8.7*	-16.8**	-2.2**	-0.5	-1.01	-0.46**	1.517
ANDCP-8-1 x GP-664	-3.4	8.5	-0.32	-6.0	-7.4	5.8	-1.5**	0.3	-1.50	-0.07	-0.733
ANDCP-8-1 x DCS-84	-8.3	10.6	-2.98**	-14.9**	16.4**	4.5	3.7**	1.5	0.66	-0.00	0.108
ANDCP-8-1 x DCS-9	0.5	-30.9**	-0.35	-0.1	-13.8**	-1.8	0.1	0.5	-0.11	0.17	-0.275
ANDCP-8-1 x RG-631	4.1	5.3	0.60	6.7	-2.3	3.0	-0.6	-2.5	-1.20	0.08	-0.34
ANDCP-8-1 x RG-3041	-3.3	-2.3	-0.85	-6.7	2.5	-14.4**	-1.0	0.8	0.47	0.07	0.10
Geeta x GP-525	-5.6	-17.7**	0.13	-17.0**	-2.9	11.0**	-1.1*	-0.2	-3.09**	-0.10	0.51
Geeta x GP-532	-3.2	7.1	0.40	-16.9**	-7.1	13.8**	0.5	-0.8	3.42**	0.16	0.04
Geeta x GP-664	0.1	12.3	-0.84	9.6	-3.3	-7.53*	0.5	-0.2	-0.20	-0.18*	-0.60
Geeta x DCS-84	-11.8*	0.4	-0.57	6.3	-4.3	-9.52**	-2.3**	0.3	-3.56**	-0.01	-0.23
Geeta x DCS-9	-0.3	2.9	-0.77	20.4**	6.8	-13.25**	1.6**	-1.8	0.55	0.06	-0.14
Geeta x RG-631	9.3	-12.9	1.41*	-1.0	5.9	-1.87	1.1	1.5	1.27	0.07	0.55
Geeta x RG-3041	11.6*	7.8	0.25	-1.5	4.8	7.36*	-0.3	1.4	1.60	0.01	-0.13
S. E. (Sij)	4.7	6.5	0.63	5.1	3.9	3.50	0.5	1.3	0.91	0.08	1.22
CD at 5%	9.4	13.1	1.26	10.2	7.0	7.03	1.1	2.6	1.83	0.17	2.45

*, ** Significant at 5% and 1% levels of probability, respectively

Table 5: Best heterotic crosses and their performance for seed yield and related parameters in castor

Sr. No.	Promising Hybrids	Seed yield (kg)	Heterosis (%)		*Per se*		GCA effects		SCA effects	Significant standard heterosis in other traits in desired direction over GCH-7
			Better Parent Heterosis	Standard Heterosis	P_1	P_2	P_1	P_2		
1	ANDCP8-1 × GP-525	1.98	27.66**	24.0**	1.57	1.42	0.006	0.369**	0.20*	DF, DM, LS,CS, ES,SW, VW
2	SKP-84 × GP-525	1.95	36.36**	21.9**	1.46	1.42	0.154**	0.369**	0.05	DF, ND, PH, LS, CS, ES, SW
3	SKP-84 ×GP-532	1.91	31.82**	19.2*	1.46	1.44	0.154**	0.169**	0.18*	DM, PH, LS,CS, ES, SW
4	SKP-84 ×GP-664	1.86	11.76	16.3*	1.46	1.70	0.154**	0.077	0.24*	PH, LS, CS, ES, SW

*, ** Significant at 5% and 1% levels of probability, respectively

Conclusion

Combining ability analysis of theses crosses revealed that *per se* performance of parent was not always reflected in high GCA effects. However, this cannot be taken as a rule because parents or genotypes with high *per se* performance need not always be good general combiners. This could be attributed due to the intra and/or inter-allelic interaction of genes concerned with the trait modified by environmental factors (Dabholkar 1999 and Punewar *et al*. 2017) [21]. Therefore, parents should be selected on the basis of *per se* performance rather than GCA effects. In general, the crosses, which exhibited high SCA effect did not always involved both good general combining parents with high GCA effect, there by suggesting importance of intra as well as inter-allelic interactions. The high SCA effect of crosses in general corresponded to their high heterotic response, but these might also be accompanied by poor and/or average gca effect of the parents. It is therefore, more desirable to select crosses based on the *per se* performance rather than magnitude of SCA effects.

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