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Studies on Combining Ability and Gene Action for Seed Yield and Architectural Traits in Castor (*Ricinus communis* L.)

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The analysis of variance for combining ability revealed that mean square values due to both parents and hybrids were significant for all the characters suggesting an importance of both additive and non-additive gene effects for the inheritance of studied characters. However, potence ratio and predictability ratio showed prime importance of additive gene effect for the characters *viz.,* days to 50 % flowering of primary raceme, plant height up to primary raceme, number of nodes up to primary raceme, number of effective branches per plant, length of primary raceme, effective length of primary raceme, number of capsules on primary raceme, number of secondary spikes per plant, total number of capsules per plant, test weight of 100 kernels, kernel length, kernel width, seed yield per plant and oil content; while, non-additive gene action was preponded for volume weight. Whereas, for the characters *viz.,* number of tertiary spikes per plant, days to 50% maturity of primary raceme and shelling out turn, the value of predictability ratio was close to one half indicating importance of both additive and non additive gene effects. In respect to gca effect of parents, the results revealed that for seed yield per plant, parents namely ANDCI 10-12, ANDCI 8, ANDCI 10-4 and ANDCI 10-3 were good general combiners. These inbreds were also good general combiners for length of primary raceme, effective length of primary raceme, total number of capsules on primary raceme and total number of capsules per plant. Among the crosses, crosses namely ANDCI 10-1 x ANDCI 9, ANDCI 10-12 x ANDCI 10-11, ANDCI 8 x ANDCI 10-3 and ANDCI 8 x ANDCI 10-11 which depicted significant and positive sca effect for seed yield and its contributing traits. In general the hybrids, which exhibited high sca effect, did not always involve both good general combiner parents with high gca effect, there by suggesting importance of both intra and inter-allelic interactions. These cross combinations could be utilized for further use in breeding programme for amelioration of seed yield and other desirable characters in castor.

Keywords: Diallel, Combining ability, Gene action and Castor

Castor (*Ricinus communis* L.) is a non-edible oil crop has an industrial importance and by export of seed, oil and its derivatives to other part of the world and dominating International market, India earns significance and valuable foreign exchange. In castor, its monoecious nature favours cross pollination and it is up to the extent of 50 per cent. Castor seed contains 47 to 55 per cent oil[1]. Castor is grown in tropical, subtropical and temperate climates and almost cultivated in 30 different countries. Among those; India, Brazil and China are major castor growing countries. At present, India is a world leader in castor production and sole exporter of castor oil, seed, seed cake and some derivatives. In India major castor growing states are Gujarat, Andhra Pradesh, Rajasthan,

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Karnataka and Tamil Nadu. Gujarat ranks first in both area and production. In Gujarat it is grown in 7.15 lakh hectares and production is 14.56 lakh tonnes with the productivity of 2036 kg/ha[2].

Castor is usually cultivated as a hybrid in India, as hybrids give significantly higher yields than pure lines or varieties[3,4]. Higher magnitude of heterotic effects and superior hybrids can be developed by combining diverse parents. In genetic improvement of different attributes of castor, selection of suitable parents is preliminary approach, which will lead to development of better hybrids. For that information based on *per se* performance of parents along with their general combining ability effect is more reliable. However, information on magnitude of heterotic effects, specific combining ability effect of hybrids and type of gene action involved for inheritance of yield and its component characters would be of immense value in selecting appropriate parents and beneficial cross combinations for commercial exploitation of hybrid vigour and also in formulating appropriate future breeding programme of castor. Therefore, the proposed investigation was planned and executed to assess the nature of gene action involved and combining ability of parental genotypes for various traits to drive productive hybrids in castor.

MATERIALS AND METHODS

The experimental material was developed by using 10 x 10 diallel excluding reciprocals among inbreds (monoecious lines) at Regional Research Station, Anand Agricultural University, Anand (Gujarat). All the genotypes (45 hybrids, 10 parents and one standard check hybrid) were grown in Randomized Complete Block Design with three replications during *kharif* season of the year 2012-2013. Each genotype was grown in a single row of 10 plants with a spacing of 120 cm between rows and 60 cm between plants. The guard rows were provided on all sides of each block. All recommended agronomical and plant protection measures were followed to raise healthy crop. Data were recorded on five randomly selected plants from each net plot of parents and F_1s in all the three replications. Mean value on per plant basis were recorded for various characters *viz*., days to 50 % flowering as well as maturity of primary raceme, plant height up to primary raceme (cm), number of nodes up to primary raceme, number of effective branches per plant, length of primary raceme (cm), effective length of primary raceme (cm), number of capsules on primary raceme, number of secondary as well as tertiary spikes per plant, total number of capsules per plant, shelling out turn (g), test weight of 100 kernels (g), kernel length (mm), kernel width (mm), volume weight (g), seed yield per plant (g) and oil content (%). The observations on days to 50% flowering and days to 50% maturity of primary raceme were recorded on plot basis. The oil content of kernels was measured by Nuclear Magnetic Resonance (NMR) technique. Combining ability analysis was performed on data obtained for parents and F_1S following[5] Model-I and method-II.

RESULTS AND DISCUSSION

The results obtained under the present investigation are presented in Table 1 to 5. The analysis of variance for combining ability (Table 1) revealed that the estimates of both σ^2_{GCA} and σ^2_{SCA} were significant for all the characters, revealing importance of both additive and non-additive genetic variances for the inheritance of traits under investigation.

The magnitude of either of component of genetic variance could be judged from the estimates of potence ratio and predictability ratio. Above one half value of predictability ratio revealed predominance of additive gene action for the characters *viz*., days to 50% flowering of primary raceme, plant height up to primary raceme, number of nodes up to primary raceme, number of effective branches per plant, length of primary raceme, effective length of primary raceme, number of capsules on primary raceme, number of secondary spikes per plant, total number of capsules per plant, test weight of 100 kernels, kernel length, kernel width, seed yield per plant and oil content. Similar results for effective length of primary raceme were reported by[6,7] and [8]; for test weight of 100 kernel by[9] were well documented. While, non-additive gene action was of prime importance for volume weight as the value of predictability ratio was less than one half. Whereas, for the characters *viz*., number of tertiary spikes per plant, days to 50% maturity of primary raceme and shelling out turn, the value of predictability ratio was close to one

Table 1. Analysis of variance for combining ability for various characters in castor

Source of variation	d.f.	Days to 50 % flowering of primary raceme	Plant height up to primary raceme	Number of nodes up to primary raceme	Number of effective branches per plant	Length of primary raceme	Effective length of primary raceme	Number of capsules on primary raceme	Number of secondary spikes per plant	Number of tertiary spikes per plant
Mean squares										
GCA (Parents)	9	59.18**	1109.88**	12.21**	40.35**	290.79**	346.22**	867.66**	7.56**	9.57**
SCA (Hybrids)	44	7.25**	46.57**	0.35**	4.56**	30.34**	32.51**	63.93**	1.03**	1.77**
Error	106	0.81	10.32	0.10	0.77	5.59	5.66	12.02	0.11	0.14
Estimates of components of genetic variance and related parameters										
σ^2_{GCA} (Σgi^2)		4.86**	91.63**	1.01**	3.29**	23.76**	28.38**	71.30**	0.62**	0.78**
σ^2_{SCA} (Σgi^2)		6.44**	36.25**	0.25**	3.79**	24.74**	26.84**	51.91**	0.91**	1.62**
Potence ratio		3.69	12.35	19.75	4.24	4.70	5.17	6.72	3.33	2.35
Predictability ratio		0.60	0.83	0.88	0.63	0.65	0.67	0.73	0.57	0.49
s^2A		9.73	183.26	2.01	6.59	47.53	56.76	142.60	1.24	1.57
s^2D		6.44	36.25	0.25	3.79	24.74	26.84	51.91	0.91	1.62
$(\sigma^2D/\sigma^2A)^{0.5}$		0.81	0.44	0.35	0.75	0.72	0.69	0.60	0.85	1.01

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

Table 1. Continue…

Source of variation	d.f.	Total number of capsules per plant	Days to 50 % maturity of primary raceme	Shelling out turn	Test weight of 100 kernels	Kernel length	Kernel width	Volume weight	Seed yield per plant	Oil content
Mean squares										
GCA	9	3295.82**	160.77**	5.47**	31.80**	0.57**	0.69**	1293.24**	2933.43**	11.90**
SCA	44	349.28**	28.95**	1.61**	2.31**	0.07**	0.04**	334.45**	309.64**	1.15**
Error	106	70.99	2.544	0.91	0.200	0.03	0.008	32.93	134.77	0.09
Estimates of components of genetic variance and related parameters										
σ^2gca (Σgi^2)		268.73**	15.42**	0.37**	2.63**	0.04**	0.05**	105.02**	233.22**	0.98**
σ^2sca (Σsij^2)		278.29**	26.45**	0.69**	2.11**	0.03**	0.03**	301.52**	174.86**	1.05**
Potence ratio		4.72	2.85	2.62	6.09	6.52	8.15	1.70	6.52	4.56
Predictability ratio		0.66	0.54	0.52	0.71	0.71	0.77	0.41	0.72	0.65
σ^2A		537.47	30.83	0.75	5.26	0.08	0.11	210.05	466.44	1.96
σ^2D		278.29	26.45	0.69	2.11	0.03	0.03	301.52	174.86	1.05
$(\sigma^2D/\sigma^2A)^{0.5}$		0.72	0.93	0.95	0.63	0.63	0.54	1.19	0.61	0.73

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

Table 2. Estimates of General Combining Ability (GCA) effect of parents for various characters in castor

Parents	Code	Days to 50 % flowering of primary raceme	Plant height up to primary raceme	Number of nodes up to primary raceme	Number of effective branches per plant	Length of primary raceme	Effective length of primary raceme	Number of capsules on primary raceme	Number of secondary spikes per plant	Number of tertiary spikes per plant
SKI 215	P_1	3.11**	10.17**	0.83**	3.00**	-2.07**	-2.30**	-7.71**	1.32**	1.29**
JI 360	P_2	-0.92**	-5.27**	-0.30**	-1.65**	-0.71	-0.57	-4.52**	-0.59**	-0.84**
ANDCI 8	P_3	0.50*	5.97**	0.81**	-1.19**	8.80**	9.14**	8.84**	-0.05	-0.70**
ANDCI 10-04	P_4	0.94**	8.90**	0.76**	-0.03	3.48**	4.17**	9.52**	0.43**	-0.66**
ANDCI 10-3	P_5	-0.72**	1.30	0.21*	1.57**	1.53*	2.12**	6.62**	0.87**	0.87**
ANDCI 10-12	P_6	-0.53*	8.88**	0.55**	-1.24**	2.50**	3.69**	12.27**	-0.58**	-0.35**
ANDCI 10-1	P_7	2.03**	-10.92**	0.21*	-1.19**	0.15	-0.66	-4.21**	-0.65**	-0.41**
ANDCI 10-11	P_8	-5.06**	-19.63**	-2.50**	-2.48**	-10.38**	-11.39**	-12.08**	-1.31**	-1.05**
ANDCI 9	P_9	1.33**	0.97	0.14	2.06**	-2.64**	-1.86**	-2.64**	0.33**	1.02**
ANDCI 1	P_{10}	-0.69**	-0.35	-0.71**	1.16**	-0.66	-2.34**	-6.10**	0.22*	0.84**
Range of GCAeffects	Min.	-5.06	-19.63	-2.50	-2.48	-10.38	-11.39	-12.08	-1.31	-1.05
	Max.	3.11	10.17	0.83	3.00	8.80	9.14	12.27	1.32	1.29
S.E (gi)±		0.24	0.88	0.08	0.24	0.64	0.65	0.94	0.09	0.10
S.E.(gi - gj) ±		0.36	1.31	0.13	0.35	0.96	0.97	1.41	0.13	0.15
C.D. 0.05 (gi)		0.47	1.72	0.15	0.47	1.25	1.27	1.84	0.17	0.20
C.D. 0.05 (gi - gj)		0.71	2.57	0.25	0.69	1.88	1.90	2.76	0.25	0.29

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

Table 2 : Continue…………..

Parents	Code	Total number of capsules per plant	Days to 50 % maturity of primary raceme	Shelling out turn	Test weight of 100 kernels	Kernel length	Kernel width	Volume weight	Seed yield per plant	Oil content
SKI 215	P_1	-10.28**	6.77**	0.40	1.92**	-0.08	0.34**	-8.28**	6.25*	1.07**
JI 360	P_2	-15.04**	2.27**	1.25**	2.84**	-0.16**	0.41**	-7.79**	-2.39	0.39**
ANDCI 8	P_3	11.50**	-0.39	0.41	0.61**	0.39**	-0.01	10.82**	16.72**	0.28**
ANDCI 10-04	P_4	16.21**	-0.84	-0.75**	-1.62**	0.12*	-0.33**	5.49**	10.72**	-0.57**
ANDCI 10-3	P_5	17.57**	-0.42	-0.04	-2.04**	-0.38**	-0.30**	1.08	7.86*	0.13
ANDCI 10-12	P_6	21.14**	-5.06**	-0.06	0.15	0.24**	-0.03	-4.18**	17.45**	-1.09**
ANDCI 10-1	P_7	-8.95**	4.82**	0.59*	0.26*	-0.01	0.13**	6.02**	-6.63*	0.82**
ANDCI 10-11	P_8	-28.62**	-5.28**	-0.91**	-1.34**	-0.09	-0.08**	-21.62**	-35.21**	-2.12**
ANDCI 9	P_9	3.32	1.30**	-0.66*	-1.57**	-0.12*	-0.08**	8.65**	-6.61*	0.90**
ANDCI 1	P_{10}	-6.85*	-3.17**	-0.22	0.78**	0.08	-0.04	9.81**	-8.16*	0.18*
Range of GCA effects	Min.	-28.62	-5.28	-0.91	-2.04	-0.38	-0.33	-21.62	-35.21	-2.12
	Max.	21.14	6.77	1.25	2.84	0.39	0.41	10.82	17.45	1.07
S.E (gi) ±		2.73	0.43	0.26	0.12	0.05	0.03	1.57	3.17	0.08
S.E. (gi-gj) ±		4.07	0.65	0.39	0.18	0.08	0.04	2.34	4.73	0.12
C.D. 0.05 (gi)		5.35	0.84	0.50	0.23	0.10	0.06	3.07	6.21	0.15
C.D. 0.05 (gi-gj)		7.98	1.27	0.76	0.35	0.16	0.08	4.59	9.27	0.23

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

half indicating equal importance of both additive and non additive gene effects.

An overall appraisal of general combining ability effects of parents (Table 2) *viz.*, ANDCI 10-12, revealed that for kernel yield per plant, parents *viz.* ANDCI 10-12, ANDCI 8, ANDCI 10-4, ANDCI 10-3 and SKI 215 were good general combiners and parent JI 360 was average general combiner; whereas, rest of the parents were poor general combiners. The parental genotypes namely, ANDCI10-12, ANDCI 8, ANDCI 10-4, ANDCI10-3 were also good general combiner for length of primary raceme, number of capsules on primary raceme and total number of capsules per plant.

The parent JI 360 was average general combiner for seed yield per plant, but it was good general combiner for days to 50 % flowering of primary raceme, plant height up to primary raceme, number of nodes up to primary raceme, shelling out turn, test weight of 100 kernels, kernel width and oil content. The above results revealed that parents, which were good general combiner for seed yield per plant were also good or average general combiner for most of the yield component characters like length of primary raceme, effective length of primary raceme, number of capsules on primary raceme and total number of capsules per plant.

In respect to gca effect of parents involved in a particular cross, crosses could be grouped into resultant of six different categories of good, average and poor general combiner parents *viz.*, G x G, G x A, A x A, A x P and P x P (Table 3). In general, the crosses, which exhibited high sca effect did not always involved both good general combiner 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.

The top ranking three parental genotypes

Table 3. Summary of combining ability effects of parents for various characters in castor

Parents	Code	Days to 50% flowering of primary raceme	Plant height up to primary raceme	Number of nodes up to primary raceme	Number of effective branches per plant	Length of primary raceme	Effective length of primary raceme	Number of capsules on primary raceme	Number of secondary spikes per plant	Number of tertiary spikes per plant	Total number of capsules per plant	Days to 50 % maturity of primary raceme	Shelling out turn	Test weight of 100 kernels	Kernel length	Kernel width	Volume weight	Kernel yield per plant	Oil content
SKI 215	P_1	P	P	P	G	P	P	P	G	G	P	P	A	G	A	G	P	G	G
JI 360	P_2	G	G	G	P	P	A	P	P	P	P	P	G	G	P	G	P	A	G
ANDCI 8	P_3	P	P	P	P	G	G	G	A	P	G	A	A	G	G	A	G	G	G
ANDCI 10-04	P_4	P	P	P	A	G	G	G	G	P	G	A	P	P	G	P	G	G	P
ANDCI 10-3	P_5	G	A	P	G	G	G	G	G	G	G	A	A	P	P	P	A	G	A
ANDCI 10-12	P_6	G	P	P	P	G	G	G	P	P	G	G	A	A	G	A	P	G	P
ANDCI 10-1	P_7	P	G	P	P	A	A	P	P	P	P	P	G	G	A	G	G	P	A
ANDCI 10-11	P_8	G	G	G	P	P	P	P	P	P	P	G	P	P	P	P	P	P	P
ANDCI 9	P_9	P	A	A	G	P	P	P	G	G	A	P	P	P	P	P	G	P	G
ANDCI 1	P_{10}	G	A	G	G	P	P	P	G	G	P	G	A	A	A	A	G	P	G

G = Good general combiner; However, dark letter suggest the best general combiner
A = Average general combiner
P = Poor general combiner

Table 4. Top three parents with respect to their *per se* performance and gca effect for various characters in castor

Characters	Days to 50 % flowering of primary raceme	Plant height up to primary raceme	Number of nodes up to primary raceme	Number of effective branches per plant	Length of primary raceme	Effective length of primary raceme	Number of capsules on primary raceme	Number of secondary spikes per plant	Number of tertiary spikes per plant
per se performance	ANDCI 10-11	ANDCI 10-11	ANDCI 10-11	SKI 215	ANDCI 8	ANDCI 8	ANDCI 8	SKI 215	SKI 215
	JI 360	ANDCI 10-1	JI 360	ANDCI 9	ANDCI 1	ANDCI 10-04	ANDCI 10-12	ANDCI 1	ANDCI 1
	ANDCI 10-12	JI 360	ANDCI 1	ANDCI 10-3	ANDCI 10-04	ANDCI 10-12	ANDCI 10-04	ANDCI 10-3	ANDCI 10-3
gca effect	ANDCI 10-11	ANDCI 10-11	ANDCI 10-11	SKI 215	ANDCI 8	ANDCI 8	ANDCI 10-12	SKI 215	SKI 215
	JI 360	ANDCI -10-1	ANDCI 1	ANDCI 9	ANDCI 10-04	ANDCI 10-04	ANDCI 10-04	ANDCI 10-3	ANDCI 9
	ANDCI 10-3	JI 360	JI 360	ANDCI 10-3	ANDCI 10-12	ANDCI 10-12	ANDCI 8	ANDCI 10-04	ANDCI 10-3
Characters	Total number of capsules per plant	Days to 50 % maturity of primary raceme	Shelling out turn	Test weight of 100 kernels	Kernel length	Kernel width	Volume weight	Kernel yield per plant	Oil content
per se performance	ANDCI 10-04	ANDCI 10-12	JI 360	JI 360	ANDCI 10-12	JI 360	ANDCI 8	ANDCI 10-12	SKI 215
	ANDCI 10-12	ANDCI 10-11	ANDCI 10-1	ANDCI 1	ANDCI 10-04	SKI 215	ANDCI 10-04	ANDCI 8	ANDCI 8
	ANDCI 10-3	ANDCI 1	ANDCI 8	SKI 215	ANDCI 8	ANDCI 10-1	ANDCI 1	SKI 215	ANDCI 9
gca effect	ANDCI 10-12	ANDCI 10-11	JI 360	JI 360	ANDCI 8	JI 360	ANDCI 8	ANDCI 10-12	SKI 215
	ANDCI 10-3	ANDCI 10-12	ANDCI 8	SKI 215	ANDCI 10-12	SKI 215	ANDCI 1	ANDCI 8	ANDCI 9
	ANDCI 10-04	ANDCI 10-1	ANDCI 1	ANDCI 1	ANDCI 10-04	ANDCI 10-1	ANDCI 9	ANDCI 10-04	ANDCI 10-1

Table 5. Top three crosses with respect to their *per se* performance and SCA effects for various characters of castor

Character	*Per se* performance	SCA effect
Days to 50 % flowering of primary raceme	ANDCI 10-12 X ANDCI 10-11	ANDCI 10-12 X ANDCI 10-11
	ANDCI 10-04 X ANDCI 10-11	JI 360 X ANDCI 1
	ANDCI 10-3 X ANDCI 10-11	ANDCI 10-04 X ANDCI 10-11
Plant height up to primary raceme	ANDCI 10-3 X ANDCI 10-11	ANDCI 10-12 X ANDCI 10-11
	ANDCI 10-12 X ANDCI 10-11	ANDCI 8 X ANDCI 10-12
	ANDCI 10-11 X ANDCI 1	SKI 215 X ANDCI 10-04
Number of nodes up to primary raceme	ANDCI 10-11 X ANDCI 1	SKI 215 X ANDCI 10-11
	SKI 215 X ANDCI 10-11	ANDCI 10-1 X ANDCI 9
	ANDCI 10-12 X ANDCI 10-11	SKI 215 X ANDCI 1
Number of effective branches per plant	SKI 215 X ANDCI 9	ANDCI 10-04 X ANDCI 10-1
	ANDCI 9 X ANDCI 1	ANDCI 10-12 X ANDCI 10-11
	ANDCI 10-04 X ANDCI 10-3	ANDCI 8 X ANDCI 10-11
Length of primary raceme	ANDCI 8 X ANDCI 10-3	JI 360 X ANDCI 10-1
	ANDCI 8 X ANDCI 10-12	ANDCI 8 X ANDCI 10-11
	ANDCI 8 X ANDCI 9	ANDCI 10-04 X ANDCI 10-11
Effective length of primary raceme	ANDCI 8 X ANDCI 10-3	ANDCI 10-04 X ANDCI 10-11
	ANDCI 10-3 X ANDCI 10-12	ANDCI 10-04 X ANDCI 10-1
	ANDCI 8 X ANDCI 10-12	ANDCI 10-12 X ANDCI 10-11
Number of capsules on primary raceme	ANDCI 10-3 X ANDCI 10-12	ANDCI 10-12 X ANDCI 10-11
	ANDCI 8 X ANDCI 10-3	JI 360 X ANDCI 10-12
	ANDCI 10-12 X ANDCI 10-11	ANDCI 10-1 X ANDCI 10-11
Number of secondary spikes per plant	SKI 215 X ANDCI 10-1	JI 360 X ANDCI 8
	SKI 215 X ANDCI 8	ANDCI 10-12 X ANDCI 10-11
	SKI 215 X ANDCI 10-3	SKI 215 X ANDCI 10-1
Number of tertiary spikes per plant	SKI 215 X ANDCI 9	ANDCI 10-04 X ANDCI 10-1
	ANDCI 9 X ANDCI 1	ANDCI 10-12 X ANDCI 10-11
	ANDCI 10-04 X ANDCI 10-3	ANDCI 10-11 X ANDCI 9
Total number of capsules per plant	ANDCI 10-3 X ANDCI 10-12	ANDCI 10-1 X ANDCI 9
	ANDCI 8 X ANDCI 10-12	ANDCI 8 X ANDCI 10-11
	ANDCI 10-04 X ANDCI 10-1	ANDCI 10-04 X ANDCI 10-1
Days to 50 % maturity of primary raceme	ANDCI 10-12 X ANDCI 10-11	ANDCI 8 X ANDCI 10-12
	ANDCI 8 X ANDCI 10-12	ANDCI 10-04 X ANDCI 10-11
	ANDCI 10-04 X ANDCI 10-11	ANDCI 10-12 X ANDCI 10-11
Shelling out turn	JI 360 X ANDCI 1	ANDCI 10-11 X ANDCI 9
	ANDCI 10-3 X ANDCI 10-1	ANDCI 10-04 X ANDCI 10-3
	JI 360 X ANDCI 10-1	ANDCI 10-3 X ANDCI 10-1
Test weight of 100 kernels	SKI 215 X ANDCI 1	ANDCI 8 X ANDCI 10-12
	JI 360 X ANDCI 10-1	SKI 215 X ANDCI 1
	SKI 215 X JI 360	ANDCI 10-11 X ANDCI 9
Kernel length	ANDCI 10-12 X ANDCI 9	ANDCI 10-3 X ANDCI 1
	ANDCI 8 X ANDCI 10-1	ANDCI 10-11 X ANDCI 9
	ANDCI 8 X ANDCI 10-12	ANDCI 10-12 X ANDCI 1
Kernel width	SKI 215 X JI 360	ANDCI 8 X ANDCI 10-3
	SKI 215 X ANDCI 1	SKI 215 X ANDCI 1
	JI 360 X ANDCI 10-11	JI 360 X ANDCI 10-04
Volume weight	ANDCI 8 X ANDCI 10-04	ANDCI 10-11 X ANDCI 9
	ANDCI 8 X ANDCI 1	ANDCI 10-11 X ANDCI 1
	ANDCI 10-04 X ANDCI 10-1	JI 360 X ANDCI 10-12
Seed yield per plant	ANDCI 8 X ANDCI 10-04	ANDCI 10-1 X ANDCI 9
	ANDCI 8 X ANDCI 10-3	ANDCI 10-12 X ANDCI 10-11
	ANDCI 8 X ANDCI 10-12	ANDCI 8 X ANDCI 10-04
Oil content	SKI 215 X ANDCI 9	ANDCI 10-11 X ANDCI 1
	JI 360 X ANDCI 10-1	ANDCI 10-12 X ANDCI 10-11
	ANDCI 10-1 X ANDCI 10-11	JI 360 X ANDCI 10-12

on the basis of their *per se* performance and general combing ability effects for seed yield per plant and its component characters are presented in Table 4. The *per se* performance of parents along with their gca effect could be a better criteria for selection of superior parent/s in future breeding programme. In present investigation, the results revealed that the most of the parents had relatively high degree of correspondence between *per se* performance and their gca effects for almost all the characters, which could be ascribed to existence of genes, which showed additivity. Therefore, in selection of parents for varietal development programme due weightage should also be given to *per se* performance along with their gca effect[10,11].

In the present investigation the top three crosses based on their per se performance and specific combining ability effects for seed and its related traits are showed in Table 5. The result indicated that for seed yield per plant total five crosses exhibited significant positive sca effect; and out of ten parents, seven parents involved in these crosses, of which four parents *viz.*, ANDCI 8, ANDCI 10-04, ANDCI 10-3 and ANDCI 10-12 were good general combiners and three parents *viz.*, ANDCI 10-1, ANDCI 10-11and ANDCI 9 were poor general combiners, therefore, cross combinations were of resultant of P x P, G x P and G x G gca effect of parents and high sca or heterotic effects could be because of intra and inter allelic interactions. It is in conformity with the findings of [9,12,13] and[14].

Among the crosses, which showed significant and positive sca effect for seed yield per plant, crosses ANDCI 10-1 x ANDCI 9 and ANDCI 10-12 x ANDCI 10-11 were good specific combiner for number of nodes up to primary raceme, number of secondary as well as tertiary spikes per plant, days to 50 % flowering of primary raceme, plant height up to primary raceme and days to 50 % maturity of primary raceme. Analogous results of significant sca effect for yield contributing characters were also reported by[12, 15 and 16].

Among the other good specific combiner crosses for seed yield, cross ANDCI 8 x ANDCI 10-3 was also good specific combiner for kernel width and poor specific combiner for days to 50% flowering of primary raceme, number of capsules on primary raceme, shelling out turn and test weight as well as volume weight, while it was average specific combiner for rest of the characters. The cross ANDCI 8 x ANDCI 10-11 was good specific combiner for number of effective branches per plant, length of primary raceme, effective length of primary raceme, number of tertiary spikes per plant, total number of capsules per plant, test weight and oil content and it was poor specific combiner for number of capsules on primary raceme, while it was average specific combiner for rest of the characters. The crosses exhibited high sca effect for seed yield per plant also registered desirable sca effect for at least two yield component characters, but those might not necessarily have higher sca effect for the said characters, which suggested cumulative effect of various yield contributing attributes towards high sca effect for seed yield and thereby high heterotic effects as well. The most common component characters, which showed desirable sca effects were number of secondary as well as tertiary spikes per plant, effective length of primary raceme, number of capsules on primary raceme and total number of capsules per plant. These overall results suggested that information on gca of the parents should be considered along with sca effects and per se performance of hybrid for predicting the value of any hybrid.

CONCLUSION

The parents ANDCI 10-12, ANDCI 8, ANDCI 10-4 and ANDCI 10-3 were good general combiners whereas crosses ANDCI 10-1 x ANDCI 9, ANDCI 10-12 x ANDCI 10-11, ANDCI 8 x ANDCI 10-3 and ANDCI 8 x ANDCI 10-11 which depicted significant and positive sca effect for seed yield and yield contributing traits. Thus these crosses could be utilized for further breeding programmes for amelioration of seed yield and drive productive hybrids in castor.

REFERENCES

1. Jeong, G.T., Park, D.H. Optimization of biodiesel production from castor oil using response surface methodology. *Appl. Biochem. Biotechnol.*,2009; **156**: 431– 441.
2. Area, production and productivity of oilseed crop. Department of Agriculture and Co-operation, Government of India, 2015. (*http://Agricop.nic.in*)

3. Birchler, J.A., Auger, D.L., Riddle, N. C. In search of the molecular basis of heterosis. *Plant Cell*, 2003; **15**: 2236-2239.
4. Reif, J.C., Gumpert, F.M., Fischer, S., Melchinger, A.E. Impact of inter population divergence on additive and dominance variance in hybrid populations. *Genetics*, 2007; **176**: 1931-1934.
5. Griffing, J.B. Concept of general and specific combining ability in relation to diallel crossing system. *Austr. J. BioI. Sci.*,1956; **9**: 463-493.
6. Kavani R.H., Golakia, P.R., Dhaduk, H.L. Combining ability analysis in castor (*Ricinus communis* L.). *J. Oilseed Research*, 2001; **18**(1): 24-27.
7. Ramu, R., Sreedhar, N., Lavanya, C., Ramesh, T. Combining ability studies in castor (*Ricinus communis* L.). *J. Oilseed Research*, 2002; **16**(2): 229-230.
8. Thakkar, D.A., Jadon, B.S., Patel, K.M. and Patel, C.J. Heterosis over environments for seed yield and other attributes in castor (*Ricinus communis* L.). *J. Oilseed Research*, 2005; **22**(2): 324-326.
9. Tank, C.J., Jaimini, S.N. and RavindraBabu, Y. Combining ability analysis over environments in castor (*Ricinus communis* L.). *Crop Res.*, 2003; **26**(1): 119-125.
10. Mehta, D.R., Vashi, P.S. and Kukadia, M.U. Combining ability for earliness traits over environment in castor. *Madras Agric. J*., 1991; **85**(3-4): 157-160.
11. Manivel, P., Hussain, H.S.J. and Raveendrran, T.S. Combining ability for earliness over environment in castor. *Madras Agric.J.*,1998; **85**(3-4): 157-160.
12. Kanwal, A.K., Chaudhary, F.P., Chaudhary, K.N. and Chaudhary, R.F. Line × Tester analysis for seed yield and its components in castor (*Ricinus communis* L.). *J. Oilseeds Res.*,2006; **23**(1): 39-42.
13. Patel, D.K., Chudhary, F.P., Patel, M.S. and Thaker, D.A. Studies on gene action and its attributing characters in castor (*Ricinus communis* L.) through Line x Tester In: National Seminar on Changing Global Vegetable Oils Scenario: Issues and Challenges Before India, January, 29-31. 2007; 51-52.
14. Patel, A.R., Patel, K.V., Patel, M.P. and Patel, J.A. Extent of heterotic effects for seed yield and component characters in castor (*Ricinus communis* L.) under rainfed condition. *J. Oilseeds Res.*, 2012; **29**(2): 149-151.
15. Solanki, S.S. and Joshi, P. Combining ability analysis over environments of diverse pistillate and male parents for seed yield and other traits in castor (*Ricinus communis* L.). *Ind. J. Genet.and Plant Breed.*, 2000; **60**(2): 201-212.
16. Barad, Y.M., Pathak, A.R., Patel, B.N. Studies on combining ability for seed yield and yield components in castor (*Ricinus communis* L). *J. Oilseeds Res.*, 2009; **26**(2): 105-108.