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Gene action and combining ability analysis for seed yield and its component traits in castor (*Ricinus communis* L.)

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Abstract
Evaluation of 20 hybrids were involving nine parents in LxT analysis, data recorded on eleven agronomical characters. Among parents, Geeta, NAUCI 8 and NAUCI 9 exhibited high *gca* effects for seed yield per plant and were observed as good general combiner for seed yield and most of its contributing characters and these may be utilized in further breeding programme. The cross combinations *viz.*, Geeta x NAUCI 6, Geeta x NAUCI 8 and SKP 72 x NAUCI 9 recorded the highest *sca* effects for seed yield per plant. The variance due to females x males was higher for all the characters as revealed by combining ability analysis signifying the preponderance of non-additive gene interactions among the hybrid under such circumstances, recurrent selection for *sca* as well as heterosis breeding seems to be the most appropriate breeding method for development of good hybrids for fulfilment of current as well as future needs.

Keywords: Combining ability, LxT, Castor, GCA, sca

Introduction

Castor (*Ricinus communis* L.) is one of the most important non-edible oilseed crops of India. Castor has 2n=20 chromosomes and belongs to monospecific genus *Ricinus* of *Euphorbiaceae* family. It has cross pollination up to the extent of 50 per cent. Because of its hardiness, castor plays an important role in the economy of arid and semi-arid regions of the country. Castor is grown in tropical, sub-tropical as well as temperate climate, covering about 30 different countries. The total world production of castor seeds is of 13.11 lakh metric tonnes from the area of 12.16 lakh ha with productivity of 1079 kg per ha. Castor is perennial crop but grown as annual crop for economic purpose. It has wide range of adaptability in varying agro climatic conditions and soils. Castor is a highly polymorphic species; normally monoecious with pistillate flowers on the upper part and staminate flowers on the lower part of raceme. Production of female and male flowers is influenced considerably by environmental conditions. With the availability of 100 per cent pistillate lines in castor, the exploitation of heterosis has become commercially feasible and economical. This spectacular improvement in the castor production was possible due to genetic enhancement in the breeding material. The Line x Tester analysis has been extensively used in almost all the major field crop in evaluation of breeding materials for general and specific combining ability. The Line x Tester method is a powerful tool in selecting appropriate parental material and predicting type of gene action involved in the inheritance of various traits. It also helps in distinguishing good as well as poor combiners. Besides its use in selection of potential parents, superior crosses and combining ability studies, it also provide information on the nature and magnitude of gene effects involved in the expression of quantitative traits. Such information has immense importance in formulating as well as executing the efficient breeding programme for obtaining maximum improvement in seed yield and its contributing traits within minimum resources and time.

Materials and Methods

The crossing programme was The carried out using 9 parents at and Castor Research Station, Navsari during *Rabi*-2017, 20 crosses were obtained in L x T analysis The experiment was laid out in a Randomized Block Design with three replications under three different locations of south Gujarat *viz.,* Pulses and Castor Research Station, Navsari, Regional Rice Research Station, Vyara and Hill Millet Research Station, Waghai in *Rabi* 2018. The parental material comprised of four female parents (lines) *viz.,* SKP-84, Geeta, SKP 72, NAUCP-1, five male parents (tester) *viz.,* NAUCI-6, NAUCI-7, NAUCI-8, NAUCI-9, DCS-107. Seeds of each hybrid, parents and checks were sown in one row of 6 meter consisting of ten plants keeping a distance of 120 cm between rows and 60 cm between plants. The border rows were provided from all sides of replications. Five random competitive plants excluding border ones were selected from each row in each replication to record observations. The eleven characters were recorded in field and mean values were subjected for statistical analysis. The combining ability analysis of data pooled over the environment was carried using the method suggested by Singh (1973), which is extension of Griffing's methods-II, Model-I (1956) to estimate the interaction of general and specific combining ability effects with environments, besides determining the significance of general and specific combining ability variance.

Result and Discussion

The mean sum of square for general and specific combining ability as well as for gca/sca ratios considering different characters studied in the present investigation and its result are presented in Table 1.

Analysis of variance for combining ability over environments revealed that mean square due to line were significant for days to 50 per cent flowering, number of nodes up to primary spike, number of capsules on primary spike and seed volume per weight in pooled analysis. The mean square due to males were significant for number of capsules on primary spike in across the environments indicating significant contribution of both females and males towards general combining ability variances for these trait. The mean squares due to females x males manifested highly significant for all traits, indicating the importance of non-additive gene action for all the traits.

The interaction mean square due to hybrids x environments were significant for most of the characters except plant height, number of effective branches per plant and seed volume per weight. The interaction mean squares due to males x environments were significant for the traits *viz.,* days to maturity and plant height. On the other hand, the mean squares due to (F x M) x environments were significant for most of the characters except days to 50 per cent flowering, days to maturity, plant height, number of effective branches per plant and seed volume per weight.

The σ 2gca were significant for days to 50 per cent flowering, days to maturity, number of nodes up to primary spike, effective length of primary spike, number of capsules on primary spike, seed volume per weight and seed yield per plant at all three locations. The σ2sca were significant for all the traits in individual environments. The estimated components of variance for hybrids x environments (σ2sij x e) was higher as compared to females x environments (σ2gi. x e) and males x environments (σ2g.j x e), which indicated that hybrids were more sensitive to environmental variation in comparison to females and males. Higher magnitude of non-additive gene action for different characters in castor have also been reported by Joshi (1993) [5], Solanki and Joshi (2000) [30], Ramesh *et al*. (2000) [26], Kavani *et al*. (2001) [8], Ramu *et al.* (2002) [27], Tank *et al.,* (2003) [34], Lavanya and Chandramohan (2003) [10], Patel (2005) [17], Parmar (2006) [16], Maheshvari (2007) [12], Barad (2008) [1], Patel *et al*. (2008) [18], Solanki *et al*. (2009) [32], Patel *et al.* (2010) [22], Patel and Chauhan (2013) [20, 21], Ramesh *et al.* (2013) [25], Patel *et al.* (2014) [19] and Dube *et al.* (2018) while, Gondaliya *et al.* (2001) [3], Patel *et al.* (2003) [23], Venkataramana *et al.* (2005) [36], Lavanya *et al.* (2006) [11], Gouri Shankar *et al*. (2009) [2], Kavani *et al*. (2010) [9], Rao *et al*. (2010) [28], Patel and Patil (2013) [20, 21], Kasture *et al.* (2014) [7] and Rajani *et al.* (2015) [24] reported significant interaction of additive and non-additive variances with environments.

Estimation of general and specific combining ability

The estimates of general combining ability (gca) effects of parents and specific combining ability (sca) effects of hybrids for eleven characters are presented in Table 2. The salient feauture of the results of general and specific combining ability effects for different characters are given below. The parents were classified as good, average and poor combiners based on estimates of general combining ability effects (Table 3).

It was observed that among nine parents, Geeta was found to be good general combiner for all the traits *viz.,* days to 50 per cent flowering, days to maturity, effective length of primary spike, number of effective branches per plant, seed volume per weight, 100 seed weight, seed yield per plant and oil content while poor combiner for rest of characters except number of capsules on primary spike which was found to be average combiner. Parent NAUCI 9 was found good general combiner for effective length of primary spike, number of capsules on primary spike, 100 seed weight, seed yield per plant and oil content whereas, it was poor combiners for days to 50 per cent flowering, days to maturity, number of nodes up to primary spike and number of effective branches per plant. The parent NAUCP-1 was found good combiner for days to 50 per cent flowering, number of effective branches per plant, seed volume per weight and 100 seed weight while average combiner for number of nodes up to primary spike, effective length of primary spike, number of capsules on primary spike, seed yield per plant and oil content except days to maturity and plant height which is found to be poor combiner. The parent NAUCI 8 was found good combiner for days to 50 per cent flowering, plant height, number of capsules on primary spike, number of effective branches per plant, seed yield per plant and oil content while poor combiner for rest of characters except effective length of primary spike, seed volume per weight and 100 seed weight which is found to be average combiner. The parent DCS 107 was found good combiner for days to maturity, 100 seed weight and oil content, while average combiner for rest of characters except days to 50 per cent flowering, plant height, number of capsules on primary spike and seed yield per plant which is found to be poor combiner. The parent, SKP 84 revealed as good combiner for days to 50 per cent flowering, plant height and number of capsules on primary spike while poor combiner for rest of characters except number of effective branches per plant, 100 seed weight and seed yield per plant which was found to be average combiner. The parent NAUCI 6 revealed as good combiner for days to 50 per cent flowering while average combiner for rest of characters except days to maturity, number of capsules on primary spike, seed yield per plant and oil content which was found to be poor combiner. The parent SKP 72 was found good combiner for plant height and number of nodes up to primary spike while poor combiner for rest of the characters. The parent NAUCI 7 was found to be poor combiner for all the characters while for number of nodes up to primary spike good combiner and for plant height average combiner. These findings are in harmony with the findings of Kavani *et al.* (2001) [8], Ramu *et al.* (2002) [27], Joshi *et al.* (2002a) [6], Tank (2003) [34], Lavanya and Chandramohan (2003) [10], Solanki *et al.* (2004) [31], Patel (2005) [17], Thakkar *et al.* (2005) [35], Lavanya *et al.* (2006) [11], Solanki (2006), Barad (2008) [1], Patel *et al.* (2008) [18], Solanki *et al.*(2009) [32], Padhar *et al.* (2010) [15], Patel and Patil (2013) [20, 21], Ramesh *et al.* (2013) [25] and Kasture *et al.* (2014) [7].

Thus, female parent Geeta while male parents NAUCI 9 and NAUCI 8 were good general combiners for seed yield and yield components and Geeta and DCS 107 for earliness, which may be utilized in crossing programme to generate the genetic variability for effective selection to develop high yielding and early maturing varieties of castor.

The estimates of *sca* effects revealed that none of the crosses were consistently superior for all the characters. (Table 4). The high yielding hybrid Geeta x NAUCI 6 had high *sca* effect for seed yield per plant. This cross also expressed high SCA effects for plant height, number of nodes up to primary spike and oil content. The high *sca* effects were accompanied by high heterosis over standard check as well as high *per se* performance. The hybrid SKP 72 x NAUCI 9 had high *per se* performance for seed yield per plant and also expressed high heterosis as well as high *sca* effect. Thus, on the basis of these results, it is expected that both these crosses may give desirable segregants in subsequent generations and hence, it would be worthwhile to use them for improvement in yield *perse*.

The *gca* effects of the parents and *sca* effects of their crosses in the present study indicated that except in few cases; the crosses between two good general combiners were not always the best specific combinations Manivel *et al.* (1998) [13], Mehta (2000) [14], Tank *et al.* (2003) [34], Parmar (2006) [16], Barad (2008) [1], Patel *et al.* (2008) [18], Sridhar *et al.* (2008) [33], Padhar *et al.* (2010) [15], Patel and Patil (2013) [20, 21], Kasture *et al.* (2014) [7] and Jalu *et al.* (2017) [4] also reported that two good combiners may not always result in high *sca* effects.

From the above discussion, it is clear that hybrids *viz.*,Geeta xNAUCI 8, Geeta x NAUCI 9, Geeta x NAUCI 6, SKP 72 x NAUCI 9 and NAUCP-1 x NAUCI 8

having high mean, high heterosis over standard checks, desirable *sca* effects for seed yield per plant (except in one hybrid) and its related traits can be exploited in practical breeding. It is also clear that the high degree of additive gene action for seed yield and its component traits observed in the present study favours mass selection and progeny selection. Hence, there may be good scope for isolation of high yielding lines in advanced generations.

Table 1: Analysis of variance showing mean squares for combining ability in castor over environments

Sources	D.F.	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of nodes up to primary spike	Effective length of primary spike (cm)	Number o capsules on primary spike	Number of effective branches per plant	Seed volume per weight (g/100ml)	100 seed weight (g)	Seed yield per plant (g)	Oil content (%)
		1721.01**	5268.63*	9503.09*	319.33**	2876.24*	7543.38**	55.39	1407.41**	132.88	3615.89	44.15
Tester effect	4	655.13	1951.13	1107.90	68.61	956.94	5890.73**	32.01	153.75	91.11	18750.30	445.48**
L*T effect	12	205.20**	1375.14**	1870.79**	44.49**	498.66**	842.53**	32.80**	206.70**	**95.40****	2625.07**	81.22**
Line effect x E	6	43.66	45.54	115.96	25.85*	38.51	111.44	0.82	28.70	42.02	1459.30	13.15
Tester effect x E	8	55.08	45.70*	178.92*	13.85	136.22	199.09	0.75	19.64	47.78	1764.05	16.84
E x L*T effect	24	31.05	18.62	74.43	9.63**	121.36**	159.69**	0.71	16.44	45.41**	1436.37**	20.27**
Pooled error	114	12.57	18.99	128.58	3.98	35.26	76.37	84.31	38.74	14.83	352.85	1.60
σ2 GCA		29.04**	88.76	127.81	4.69*	46.22*	163.45**	1.05	18.58*	2.49	268.57	6.00
σ2 SCA		21.47**	151.10**	193.52**	4.47**	50.45**	82.81**	3.52**	19.83**	9.37	257.69	8.85**
σ2 GCA/ σ2 SCA		1.36	0.59	0.66	1.04	0.92	1.97	0.30	0.93	0.27	1.04	0.68

Table 2: Estimates of general combining ability effects of parents and specific combining ability effects of hybrids over environments in castor

Sr. No.	Parents/crosses	Days to 50 per cent flowering	Days to maturity	Plant height (cm)	Number of nodes up to primary spike	Effective length of primary spike (cm)	Number of capsules on primary spike	Number of effective branches per plant	Seed volume per weight (g/100ml)	100 seed weight (g)	Seed yield per plant (g)	Oil content (%)
	Parents											
L1	SKP 84	-3.03**	1.69*	-4.02*	0.40**	-4.08**	14.60**	-0.20	-5.17**	-0.88	-0.26	-0.42*
L2	Geeta	-4.72**	-15.55**	16.60**	3.27**	11.73**	1.89	0.82**	6.25**	1.80**	10.12**	1.44**
L3	SKP 72	9.03**	9.23**	-17.75**	-3.20**	-5.86**	-16.91**	-1.49**	-4.24**	-1.95**	-11.64**	-0.79**
L4	NAUCP-IPS 1	-1.28*	4.63**	5.16**	-0.47	-1.79	0.42	0.87**	3.17**	1.03*	1.78	-0.23
T1	NAUCI 6	-6.47**	2.22**	1.01	-0.59	1.54	-9.41**	0.17	-0.29	-1.08	-7.53*	-0.77**
T2	DCS 107	2.76**	-13.03**	7.29**	-0.65	-2.08	-6.16**	0.24	0.88	1.54**	-11.14**	1.76**
T3	NAUCI 7	2.89**	4.33**	-3.44	-1.48**	-7.06**	-11.63**	-0.77**	-3.42**	-1.80**	-27.92**	-5.78**
T4	NAUCI 8	-2.30**	2.19**	-7.19**	0.68*	0.58	17.01**	1.36**	0.91	-0.44	18.92**	1.74**
T5	NAUCI 9	3.11**	4.30**	2.34	2.04**	7.03**	10.18**	-1.01**	1.92*	1.78**	27.67**	3.05**
	S.E.gi	0.73		2.39	0.43	1.41	2.08	0.22	-5.17**	0.70	3.69	0.26
	S.E.gi - gj	0.81		2.68	0.48	1.57	2.32	0.25	6.25**	0.78	4.12	0.29
	Crosses											
10	SKP 84 x NAUCI 6	-2.91*	-5.19**	5.09	3.02**	-4.33	8.21*	0.05	-6.51**	2.30*	-4.96	-0.36
11	SKP 84 x DCS 107	2.87*	-8.40**	-8.85*	-1.04	-2.78	-17.27**	0.01	-5.51**	-3.40**	5.54	0.80
12	SKP 84 x NAUCI 7	-4.16**	3.92**	4.90	1.79**	7.28**	4.98	0.34	0.24	1.66	5.21	3.73**
13	SKP 84 x NAUCI 8	-4.74**	3.72*	10.68**	-1.15	2.60	9.34*	0.80**	6.77**	-1.30	-1.29	-2.53**
14	SKP 84 x NAUCI 9	8.95**	5.94**	-11.82**	-2.62**	-2.78**	-5.27	-1.20**	5.02*	0.73	-4.49	-1.65**
15	Geeta x NAUCI 6	-1.56	20.16**	-27.50**	-3.74**	0.34	-11.53**	-1.19**	3.64	-2.74*	27.66**	4.40**

16	Geeta x DCS 107	1.33	-16.81**	13.55**	-0.02	3.01	13.33**	2.61**	-0.74	0.64	-33.95**	-0.66
17	Geeta x NAUCI 7	2.19	-14.84**	13.90**	1.59*	3.21	-1.19	-0.89**	-1.81	-5.50**	2.38	-3.63**
18	Geeta x NAUCI 8	0.83	10.30**	-0.54	0.65	-2.39	-7.72*	1.08**	-0.67	3.30**	6.33	-0.75
19	Geeta x NAUCI 9	-2.80*	1.19	0.59	1.51*	-4.17	7.11*	-1.61**	-0.41	4.30**	-2.42	0.64
20	SKP 72 x NAUCI 6	2.24	-4.39**	13.33**	1.06	5.16*	6.83*	-2.01**	5.08*	0.25	-15.03*	-3.66**
21	SKP 72 x DCS 107	-2.98*	10.97**	-1.95	1.12	-9.30**	-3.53	-0.68*	3.33	-0.51	14.92*	-0.59
22	SKP 72 x NAUCI 7	-3.56**	2.72	0.36	-0.60	1.70	0.05	1.15**	2.11	3.41**	-10.75	3.06**
23	SKP 72 x NAUCI 8	4.74**	-6.81**	-6.89	-0.33	5.66*	1.85	-1.10**	-6.53**	-1.09	-8.47	-0.44
24	SKP 72 x NAUCI 9	-0.45	-2.48	-4.85	-1.24	-3.21	-5.20	2.64**	-3.99	-2.06	19.33**	1.62**
25	NAUCP-1x NAUCI 6	2.22	-10.57**	9.07*	-0.34	-1.16	-3.51	3.15**	-2.21	0.19	-7.67	-0.38
26	NAUCP-1x DCS 107	-1.22	14.23**	-2.74	-0.06	9.07**	7.47*	-1.95**	2.93	3.27**	13.49*	0.44
27	NAUCP-1x NAUCI 7	5.53**	8.21**	-19.16**	-2.78**	-12.19**	-3.84	-0.60*	-0.54	0.42	3.16	-3.17**
28	NAUCP-1x NAUCI 8	-0.83	-7.21**	-3.25	0.83	-5.88*	-3.48	-0.78**	0.43	-0.91	3.44	3.72**
29	NAUCP-1x NAUCI 9	-5.69**	-4.66**	16.08**	2.36**	10.15**	3.36	0.18	-0.61	-2.96**	-12.42*	-0.61
	S.E.sij	1.15	1.30	3.79	0.68	2.23	3.29	0.35	1.77	1.11	5.83	0.41
	S.E.sij- sik	1.63	1.84	5.36	0.97	3.15	4.65	0.50	2.50	1.56	8.24	0.58

Table 3: Ranking of parents with respect to general combining ability effects for different characters in pooled analysis

Sr. No.	Characters/Parents	SKP 84	Geeta	SKP 72	NAUCP-1	NAUCI 6	DCS 107	NAUCI 7	NAUCI 8	NAUCI 9
1	Days to 50% flowering	G	G	P	G	G	P	P	G	P
2	Days to maturity	P	G	P	P	P	G	P	P	P
3	Plant height (cm)	G	P	G	P	A	P	A	G	A
4	Number of nodes up to primary spike	P	P	G	A	A	A	G	P	P
5	Effective length of primary spike(cm)	P	G	P	A	A	A	P	A	G
6	Number of capsules on primary spike	G	A	P	A	P	P	P	G	G
7	Number of effective branches per plant	A	G	P	G	A	A	P	G	P
8	Seed volume per weight (g/100ml)	P	G	P	G	A	A	P	A	A
9	100 seed weight (g)	A	G	P	G	A	G	P	A	G
10	Seed yield per plant (g)	A	G	P	A	P	P	P	G	G
11	Oil content (%)	P	G	P	A	P	G	P	G	G

Table 4: Best heterotic crosses and their *per se* performance with *gca* effects of parents involved and *sca* effects of these crossesfor seed yield in castor

Sr. No.	Crosses	Seed yield per plant	Better Parent heterosis (%)	Standard Heterosis -1 (%)	Standard Heterosis -2 (%)	SCA Effects	GCA effects	
							P_1	P_2
1	Geeta x NAUCI 8 (154.33) 169.89	194.56	14.52**	24.63**	16.89**	6.33	10.12" G	18.92** G
	Geeta x NAUCI 9 (154.33) 170.00	194.56	14.44**	24.63**	16.89**	-2.42	10.12** G	27.67** G
	SICP 72 x NAUCI 9 (83.22) 170.00	194.56	14.44**	24.63**	16.89**	19.33**	-11.64** P	27.67** G
4	Geeta x NAUCI 6 (154.33) 143.00	189.44	22.75**	21.35**	13.82**	27.66**	10.12** G	-/.53** P
	NAUCT-1 x NAUC1 8 (124.22) (189.44)	183.33	7.91	17.44**	10.15*	3.44	1.78 A	18.92** G

Significant at 5% level, ** Significant at 1% level

G: Good parent having significant *gca* effect in desirable direction

A: Average parent having either positive or negative but non-significant *gca* effect P: Poor parent having significant for undesirable *gca* effect

Conclusion

An overall examination of parents and their cross combination for their relative breeding value in terms of combining ability suggested that none of the parent was found to be good general combiner for all the traits studied. However, among nine parents, parents *viz.*, Geeta, NAUCI 9 and NAUCI 8 were found to be good general combiners for seed yield per plant and stable for most of the traits. Significant levels of desirable heterosis and specific combining ability on pooled basis were recorded in the cross combination Geeta x NAUCI 6 and SKP 72 x NAUCI 9.Therefore may be used in commercial exploitation of heterosis whereas, significant level of desirable heterosis and non-significant but positive specific combining ability were observed in the cross combination Geeta x NAUCI 8 and NAUCP-1 x NAUCI 8 will be used in varietal development.

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