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

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Abstract
The experimental material consisted of ten inbred lines, their 45 F_1s developed through diallel mating excluding reciprocals, were evaluated in Randomized Complete Block Design with three replications. The analysis of variance for combining ability revealed that mean squares due to both GCA and SCA were significant for all the characters except SCA for oil content, indicating the importance of both additive and non-additive gene action for the inheritance of studied characters. The estimates of σ^2gca were higher than the corresponding σ^2sca for effective length of primary raceme and oil content indicated the preponderance of additive component of genetic variance for these traits, while for number of capsules on primary raceme, number of effective branches per plant**,** **s**helling out turn,
100-seed weight and seed yield per plant non-additive component of genetic variance was predominant. Parents, PCS-124, SKI-215 and JI-35 were good general combiners for seed yield per plant and other yield contributing characters. Hybrids, SKP-84 x PCS-124, VP-1 x SKI-346 and SKP-84 x JI-35 had high *per se* performance, high heterotic effects and desired sca effects for seed yield per plant and its component characters.

Keywords: Combining ability, GCA, SCA, gene action

1. Introduction
Castor (*Ricinus communis* L.) with 2n = 20, belongs to the family Euphorbiaceae and it is indigenous to eastern Africa and most probably originated in Ethiopia. The crop is grown as an important industrial non-edible oilseeds crop. India is the world’s principal producer of castor and ranks first both in area and production. Castor productivity in India is more than world average and it ranks first among the major castor producing countries *viz*., India, China, Brazil and Thailand. The area, production and productivity of castor in India during 2017-18 were 8.23 lakh ha, 14.43 lakh tonnes and 1754 kg/ha, respectively (Anon., 2018) [2]. Gujarat, Andhra Pradesh, Rajasthan, Tamil Nadu, Karnataka, Madhya Pradesh, Uttar Pradesh, Orissa and Mahashtra are the main castor growing states in the country. In Gujarat, castor occupied about 5.96 lakh ha area during 2017-18 and production was 12.30 lakh tonnes with productivity of 2066 kg/ha (Anon., 2018) [2]. In India, castor is being grown under wide ranging environmental conditions.
Combining ability is a powerful tool to select good combiners and thus selecting the appropriate parental lines for hybridisation 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 programm (Cockerham, 1961) [5].
The diallel analysis was attempted in present investigation because of its precision and versatility. This technique provides a systematic approach for identification of superior parents and crosses which is the basic requirement on which success of a breeding programme rests and also gives an overall genetic picture of the experimental material in a single generation. With diallel analysis, it is easy to separate variation component into genotypic, phenotypic or environmental variance. It also helps to sought out genotypes that have general combining ability or specific combining ability in desirable direction. This also helps the plant breeders to know the type of gene action. With these, the plant breeders would be able to know which breeding method to be adopted in crop improvement programme.

Materials and Methods

The experimental material comprised of ten parents *viz.*, SKP-84, VP-1, JI-436,
JI-433, JI-368, SKI-346, PCS-124, JI-35, SKI-215, RG-43 and their 45 half diallel crosses. The seeds of 45 F_1 hybrids and ten parents were produced by hand emasculation-hand pollination and selfing during *Kharif* 2016-17. These 45 F_1 hybrids along with 10 parents were evaluated in randomized block design with three replications during *Kharif* 2017-18 at Main Oilseeds Research Station, Junagadh Agricultural University, Junagadh. All the recommended package of practices was adopted to raise a good crop.

Observations were recorded for various characters on five randomly selected competitive plants in each genotype in each replication. The characters *viz.*, days to 50% flowering of primary raceme, days to maturity of primary raceme, plant height up to primary raceme, number of nodes up to primary raceme, length of primary raceme, effective length of primary raceme (cm), number of effective branches per plant, number of capsules on primary raceme, shelling out turn (%), 100-seed weight (g), seed yield per plant (g) and oil content (%) were subjected to diallel analysis according to Model-I, Method-II proposed by Griffing (1956) [7]. Analysis of variance suggested by Panse and Sukhatme (1967) was followed to test the significant differences between the genotypes for all the characters.

Results and Discussions

The analysis of variance for combining ability (Table 1) revealed that general combining ability and specific combining ability variances were significant for all the characters, which indicated that both additive and non-additive gene actions were important in the inheritance of these traits. The results are in accordance with the findings of Mehta (2000) [9], Tank *et al.* (2003) [16], Solanki (2006) [15], Madariya *et al.* (2008) [8], Barad *et al.* (2009) [4], Yogitha *et al.* (2009) [18], Patel and Chauhan (2013) [12, 13], Aher *et al.* (2015) [1], Patel *et al.* (2015). The magnitude of GCA and SCA variance revealed that SCA variance was higher than their respective GCA variance for most the characters except plant height up to primary raceme, number of nodes up to primary raceme, length of primary raceme, effective length of primary raceme and oil content.

The estimate of GCA effect indicated that the parents, PCS-124, JI-35 and SKI-215 were found to be the good general combiners for seed yield and some of the yield attributing characters. For the characters related to earliness *viz.*, days to 50% flowering of primary raceme and days to maturity of primary raceme**,** JI-436, JI-433 and JI-368 were found to be good combiners and these were also good combiners for plant height up to primary raceme and number of nodes up to primary raceme. On the other hand, SKP-84, VP-1, SKI-346 and RG-43 were average combiner for seed yield but good combiners for two or more yield attributing characters (Table 3).

The information of three best performing parents and hybrids, top ranking good general combiners as well as heterotic hybrids and good specific combiners are given in Table 4. The estimates of sca effects revealed that none of the crosses was consistently superior for all the traits. Out of 45 hybrids studied, seven cross combinations exhibited significant and positive sca effects for seed yield per plant. The highest yielding hybrid
SKP-84 x PCS-124 had also registered significant and positive sca effect for seed yield per plant involving poor x good general combiner parents for seed yield per plant. The sca effect in this cross combination was also accompanied by significant and high standard heterosis for seed yield per plant and component traits like length of primary raceme and effective length of primary raceme (Table 2). This hybrid also showed significant and desirable sca effects for days to 50% flowering of primary raceme and oil content.

Likewise, the cross VP-1 x SKI-346 depicted significant and desirable sca effect for seed yield per plant, which involved average x average general combining parents and also recorded significant and positive standard heterosis for seed yield per plant. This cross exhibited significant and desirable standard heterosis for various component traits like length of primary raceme, effective length of primary raceme and number of capsules on primary raceme. This indicated the association between sca effect and heterotic values. Similar findings, as observed in present study, were also reported by Yadav *et al.* (1978) [17].

The third cross, SKP-84 x JI-35 having significant and desirable sca effect for seed yield per plant, involved poor x good combiners, also possessed desirable heterobeltiosis and standard heterosis for this trait (Table 2) and significant and desirable sca effects for days to 50% flowering of primary raceme and days to maturity of primary raceme. In general, hybrids with significant and desirable sca effect for seed yield also recorded significant and desirable sca effect for one or more of its component traits. Similar findings were also reported by Pathak and Dangaria (1987).

Out of ten top most high yielding cross combinations, four cross combinations *viz*., SKP-84 x PCS-124, VP-1 x SKI-346, SKP-84 x JI-35 and VP-1 x JI-368 also manifested the significant and desirable sca effect for seed yield per plant (Table 2), which involved poor x good, average x average, poor x good and average x average general combiners, respectively.

The involvement of good general combiners was not necessarily for the best cross combination and a poor x poor cross always a poor combination. Singh and Yadav (1981) [14], Mehta (2000) [9] and Tank *et al.* (2003) [16] also reported that two good combiners may not always result in high sca effect. Some crosses showed poor sca effect even though they involved good x good general combiners. Such results are feasible due to lack of genetic diversity between the two parents involved.

A comparison of mean performance of hybrids and their sca effect revealed that *per se* performance of crosses was not correlated with their sca effect in majority of the characters. Similar results have been reported by Dobariya *et al.* (1992) [6] and Mehta (2000) [9]. This may be due to the fact that *per se* performance is a realized value, whereas sca effect is an estimate, measured as the deviation of F_1 over parental performance.

High sca effects due to good x good combiners reflect additive x additive type of gene interaction and superiority of favorable genes contributed by the parents. In facts, in most of the cross combinations, the best specific combinations for different characters involved either good x good, good x poor, average x average and average x poor general combiners. It
indicated additive x dominance type of gene interaction, which could produce desirable types of transgressive segregants in subsequential generations. This suggested that information on gca effects should be supplemented by sca effects and hybrid performance of cross combinations to

predict the transgressive types possibly made available in segregating generations. Selection is rapid if gca effects of parents and sca effects of crosses are in the same direction.

Conclusion

None of the crosses exhibited consistently high sca effects for all the characters studied. Crosses showing high sca effects for seed yield also depicted high sca effects for one or more of yield components. The cross displaying high sca effects did not always involve parents with high gca effects, suggesting that the interallelic interactions were also important for the characters. The *Per se* performance of hybrids for various traits was not related with their sca effects. From results of combining ability, gene action and component of variance, it can be concluded that non-additive gene action was predominant for days to 50% flowering of primary raceme, days to maturity of primary raceme, number of capsules on primary raceme, number of effective branches per plant**,** **s**helling out turn, 100-seed weight and seed yield per plant, which indicated that heterosis breeding would be helpful for improving these traits. Four cross combinations *viz*., SKP-84 x PCS-124, VP-1 x SKI-346, SKP-84 x JI-35 and VP-1 x JI-368 manifested the high and desirable sca effect for seed yield per plant and along with one or more component traits.

Table 1: Analysis of variance and variance components of combining ability for different characters

Sources	d.f.	Days to 50% floweringof primary raceme		Days to maturity of primary raceme	Plant height up to primary raceme (cm)	Number of nodes up to primary raceme	Length of primary raceme (cm)		Effective length of primary raceme (cm)	
GCA	9	160.11	**	52.32**	767.34**	9.93**	333.28	**	740.15	**
SCA	45	18.08	**	29.48 **	52.00**	0.84**	25.32	**	28.07	**
Error	108	0.84		3.06	6.79	0.11	3.80		3.21	
Variance components										
σ^2 gca		13.28		4.11	63.38	0.82	27.46		61.41	
σ^2 sca		17.24		26.42	45.22	0.74	21.52		24.86	
σ^2 gca / σ^2 sca		0.77		0.15	1.40	1.11	1.27		2.47	

Table 1: Contd…

Sources	d.f.	Number of effective branches per plant	Number of capsules on primary raceme		Shelling out turn (%)		100-seed weight(g)		Seed yield per plant (g)		Oil content (%)
GCA	9	16.76 **	3656.5	**	40.24	**	11.55	**	33980.95	**	0.23**
SCA	45	6.90 **	432.88	**	9.51	**	10.93	**	10956.76	**	0.09
Error	108	1.20	16.92		2.21		1.67		2712.02		0.08
Variance components											
σ^2 gca		1.30	303.30		3.17		0.82		2605.74		0.012
σ^2 sca		5.70	415.96		7.30		9.26		8244.73		0.006
σ^2 gca / σ^2 sca		0.23	0.73		0.43		0.08		0.32		1.99

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

Table 2: Promising hybrids for seed yield per plant with heterobeltiosis (H_1), standard heterosis (H_2), their sca effects and component traits showing significant and desirable standard heterosis

Sr. No.	Hybrids	Seed yield per plant (g)	Heterosis (%) H_1 (%)	H_2 (%)		sca effects		Significant and desirable heterosis for yield attributing traits H_1 (%)	H_2 (%)
1	SKP-84 x PCS-124	589.56	27.61	48.18	**	207.46	**	ST	LR, ELR
2	VP-1 x SKI-346	569.50	30.00	43.13	*	152.68	**	EB, CR	LR, ELR, CR
3	PCS-124 x SKI-215	557.33	20.63	40.07	*	70.52		EB	ELR
4	SKP-84 x JI-35	546.07	45.32 *	37.24	*	136.72	**	-	-
5	PCS-124 X JI-35	512.03	10.83	28.69		-5.70		-	-
6	VP-1 X JI-368	510.97	49.98 *	28.42		132.14	**	-	-
7	VP-1 X JI- 35	509.70	35.64	28.10		56.14		SW	-
8	SKI-346 x PCS-124	502.47	8.76	26.29		21.47		-	-
9	VP-1 X SKI-215	499.67	55.61 *	25.58		77.03		-	LR, ELR
10	JI-35 X SKI-215	493.00	31.12	23.91		12.28		LR, ELR, SW	SW
	GCH-7	397.88	23.91	--		118.56	*		-
	S.Em		73.65	73.65					

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

LR= Length of primary raceme, ELR= Effective length of primary raceme, CR= Number of capsules on primary raceme, SW= 100 seed weight, EB= Number of effective branches per plant, ST= Shelling out turn

Table 3: Summary of general combining ability effects of the parents for different characters in castor

Parents	Days to 50% Flowering of Primary raceme	Days to maturity of primary raceme	Plant height up to Primary raceme (cm)	Number of nodes up to primary raceme	Length of Primary raceme (cm)	Effective length of Primary raceme (cm)	Number of Effective branches per plant	Number Of Capsules On Primary raceme	Shelling out turn (%)	100 seed weight (g)	Seed yield per Plant (g)	Oil content (%)
SKP-84	P	P	G	P	G	G	P	G	G	G	P	A
VP-1	G	A	G	G	G	G	P	A	G	A	A	A
JI-436	G	G	G	G	G	G	P	P	P	A	P	A
JI-433	G	G	G	G	G	G	P	G	A	A	P	P
JI-368	G	G	G	G	P	P	A	P	G	A	A	A
SKI-346	P	P	P	P	G	G	A	G	G	A	A	A
PCS-124	P	G	P	A	P	P	G	P	P	P	G	G
JI-35	P	P	P	P	P	P	G	A	P	A	G	A
SKI-215	P	A	P	P	P	A	G	P	G	G	G	A
RG-43	G	A	P	G	P	P	G	P	P	P	A	A

Table 4: Summary of three best *per se* performing parents and good general combiners along with three best hybrids based on *per se* performance and heterobeltiosis, standard heterosis and sca effects for different characters in castor

Sr. No.	Characters	Rank	Parents		Crosses			
			Per se performance	GCA effects	*Per se* performance	Heterobeltiosis	Standard Heterosis	Sca effects
1	Days to 50% flowering of primary raceme	I	RG-43	RG-43	VP-1 x RG-43	VP-1 x JI-436	VP-1 x RG-43	JI-35 x SKI-215
		II	JI-436	VP-1	JI-436 x RG-43	SKI-346 x JI-35	JI-436 x RG-43	SKP-84 x PCS-124
		III	JI-433	JI-436	VP-1 x JI-436	SKP-84 x PCS-124	VP-1 x JI-436	SKP-84 x SKI-346
2	Days to maturity of primary raceme	I	JI-433	JI-436	JI-368 x PCS-124	SKP-84 x JI-35	-	JI-35 x SKI-215
		II	JI-436	JI-433	JI-433 x SKI-346	JI-35 x SKI-215	-	SKP-84 x SKI-215
		III	JI-368	PCS-124	JI-368 x JI-35	SKI-346 x JI-35	-	JI-368 x JI-35
3	Plant height up to primary	I	VP-1	VP-1	SKP-84 x VP-1	PCS-124 x JI-35	SKP-84 x VP-1	SKP-84 x VP-1
		II	JI-436	JI-436	VP-1 x JI-436	-	VP-1 x JI-436	PCS-124 x JI-35
		III	JI-368	SKP-84	VP-1 x JI-433	-	VP-1 x JI-433	JI-35 x SKI-215
4	Number of nodes up to primary raceme	I	JI-368	RG-43	VP-1 x RG-43	JI-436 x PCS-124	VP-1 x RG-43	JI-436 x PCS-124
		II	RG-43	VP-1	VP-1 x JI-368	JI-35 x SKI-215	JI-436 x PCS-124	JI-35 x SKI-215
		III	VP-1	JI-368	JI-436 x PCS-124	-	VP-1 x JI-368	SKI-346 x JI-35
5	Length of primary raceme (cm)	I	SKP-84	SKI-346	SKP-84 x VP-1	JI-368 x PCS-124	SKP-84 x VP-1	SKP-84 x VP-1
		II	SKI-346	SKP-84	JI-436 x SKI-346	JI-368 x SKI-215	JI-436 x SKI-346	JI-433 x JI-35
		III	JI-436	VP-1	VP-1 x SKI-346	JI-35 x SKI-215	VP-1 x SKI-346	JI-35 x RG-43
6	Effective length of primary raceme (cm)	I	SKP-84	SKP-84	SKP-84 x VP-1	JI-368 x PCS-124	SKP-84 x VP-1	SKP-84 x VP-1
		II	SKI-346	SKI-346	JI-436 x SKI-346	JI-368 x SKI-215	JI-436 x SKI-346	JI-368 x SKI-215
		III	JI-436	JI-436	VP-1 x SKI-346	JI-35 x SKI-215	VP-1 x SKI-346	JI-368 x PCS-124
7	Number of Plant	I	JI-35	SKI-215	JI-35 x RG-43	VP-1 x JI-436	JI-35 x RG-43	SKP-84 x SKI-215
		II	RG-43	RG-43	VP-1 x SKI-346	VP-1 x SKI-346	-	VP-1 x SKI-346
		III	PCS-124	JI-35	PCS-124 x SKI-215	PCS-124 x SKI-215	-	SKP-84 x JI-368
8	Number of capsules on primary raceme	I	SKP-84	SKI-346	SKI-346 x SKI-215	VP-1 x SKI-346	SKI-346 x SKI-215	JI-368 x PCS-124
		II	SKI-346	SKP-84	JI-433 x SKI-346	JI-368 x PCS-124	JI-433 x SKI-346	VP-1 x PCS-124
		III	JI-433	JI-433	VP-1 x SKI-346	-	VP-1 x SKI-346	JI-436 x JI-35
9	Shelling out turn (%)	I	SKI-346	SKP-84	VP-1 x JI-433	SKP-84 x JI-433	VP-1 x JI-433	VP-1 x JI-433
		II	SKI-215	SKI-346	SKP-84 x JI-433	VP-1 x JI-433	SKP-84 x JI-433	SKP-84 x JI-433
		III	JI-368	VP-1	SKP-84 x SKI-346	SKP-84 x SKI-346	-	JI-436 x JI-433
10	100 seed weight (g)	I	SKI-346	SKP-84	JI-436 x SKI-215	JI-433 x JI-35	JI-436 x SKI-215	JI-436 x JI-433

		II	SKP-84	SKI-215	JI-436 x JI-433	JI-436 x JI-433	JI-436 x JI-433	VP-1 x JI-35
		III	VP-1	-	JI-35 x SKI-215	JI-368 x RG-43	JI-35 x SKI-215	JI-436 x SKI-215
11	Seed yield per plant (g)	I	PCS-124	PCS-124	SKP-84 x PCS-124	VP-1 x SKI-215	SKP-84 x PCS-124	SKP-84 x PCS-124
		II	SKI-346	JI-35	VP-1 x SKI-346	VP-1 x JI-368	VP-1 x SKI-346	VP-1 x SKI-346
		III	JI-35	SKI-215	PCS-124 x SKI-215	SKP-84 x JI-35	PCS-124 x SKI-215	SKP-84 x JI-35
12	Oil content (%)	I	PCS-124	PCS-124	SKP-84 x PCS-124	-	SKP-84 x PCS-124	SKP-84 x PCS-124
		II	JI-35	-	JI-368 x PCS-124	-	-	-
		III	RG-43	-	JI-368 x SKI-215	-	-	-

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