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Gene Action and Combining Ability Analysis for Seed Yield and Component Traits in Castor Genotypes

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Abstract: General and specific combining ability was studied in castor genotypes under three different environments at Mandor, Jodhpur using three lines and ten testers along with their resultant 30 hybrids and one check (GCH-8) for seed yield and yield attributing traits. Analysis of variance showed significant influence on gca (general combining ability) and sca (specific combining ability) variances for most of the characters studied. Tester MCP-1-1 was found good general combiner for seed yield at 120, 150, 180 and 210 days after sowing and for other yield determining traits. On the contrary, two testers *viz.*, MP-12-17 and MP-27-17 were found superior for overall seed yield at final harvest done at 210 days after sowing and also for some yield governing traits. Hybrids possessing high sca effects for overall seed yield were SKP-84 × MP-36-17, MCP-1-1 × MP-12-17 and DPC-15 × MP-34-17, these hybrids were found promising for high seed yield in arid regions of Rajasthan.

Key words: Castor, Gene action, Combining ability, Seed yield.

Castor (*Ricinus communis* L.) is a non-edible oilseed crop having high oil content (45-60%) which is primarily used for the manufacturing of soaps, lubricants, cosmetics and also in pharmaceutical (Olaniyan, 2010). In India, castor is cultivated in area of 0.89 million ha with 1.51 million tonns of production and 1697 kg/ha productivity (Anonymous, 2023). A warm climatic condition with low relative humidity is considered suitable for high seed yield as well as for oil production (Ueda, 1970). Optimum rainfall of 300 mm and soil pH of 6-7.3 is optimum for castor production (Nweke, 2019). Western arid regions provide favourable high temperature with low humidity throughout the growing period which lead to higher seed production (Naidu *et al.*, 2015). Use of parents having superior genetic worth ensures much better success which requires extensive assessment of existing germplasm as well as newly developed lines, which could be directly released as a cultivar after testing or as parents in subsequent breeding

Table 1. Details of parental lines with their pedigree and source

Sr. No	Genotypes	Pedigree	Source
Lines (Females)			
1.	MCP-1-1	Selection from VP-1	ARS, Mandor
2.	SKP-84	SKP-1 x VP-1	SDAU, S.K. Nagar
3.	DPC-15	NES-6 x DCS-12	IIOR, Hyderabad
Testers (Males)			
4.	MP-2-17	STV-10-05 x PVT-29-06	ARS, Mandor
5.	MP-12-17	48-1 xMP-RHC-19	ARS, Mandor
6.	MP-27-17	VP-1 x RG-1686	ARS, Mandor
7.	MP-32-17	MP-RHC-51 x BM-8-11-2-97	ARS, Mandor
8.	MP-34-17	JI-220 x DCS-9	ARS, Mandor
9.	MP-35-17	JI-220 x MI-61	ARS, Mandor
10.	MP-36-17	98 Ln 94-3 x Bm-8-11-2-97	ARS, Mandor
11.	MP-39-17	VP-1 x RG-1686	ARS, Mandor
12.	MP-41-17	JI-220 x MP-98-94-3	ARS, Mandor
13.	MP-42-17	DCS-9 x MI-61	ARS, Mandor
Check Variety			
14.	GCH-8 (C) National check	JP-96 x DCS-89	SDAU, S.K. Nagar
Hybrids			

Sr. No	Pedigree	Sr. No	Pedigree	Sr. No	Pedigree
15.	MCP-1-1 x MP-2-17	25.	SKP-84 x MP-2-17	35.	DPC-15 x MP-2-17
16.	MCP-1-1 x MP-12-17	26.	SKP-84 x MP-12-17	36.	DPC-15 x MP-12-17
17.	MCP-1-1 x MP-27-17	27.	SKP-84 x MP-27-17	37.	DPC-15 x MP-27-17
18.	MCP-1-1 x MP-32-17	28.	SKP-84 x MP-32-17	38.	DPC-15 x MP-32-17
19.	MCP-1-1 x MP-34-17	29.	SKP-84 x MP-34-17	39.	DPC-15 x MP-34-17
20.	MCP-1-1 x MP-35-17	30.	SKP-84 x MP-35-17	40.	DPC-15 x MP-35-17
21.	MCP-1-1 x MP-36-17	31.	SKP-84 x MP-36-17	41.	DPC-15 x MP-36-17
22.	MCP-1-1 x MP-39-17	32.	SKP-84 x MP-39-17	42.	DPC-15 x MP-39-17
23.	MCP-1-1 x MP-41-17	33.	SKP-84 x MP-41-17	43.	DPC-15 x MP-41-17
24.	MCP-1-1 x MP-42-17	34.	SKP-84 x MP-42-17	44.	DPC-15 x MP-42-17

programme (Patel *et al.,* 2018). Therefore, assessment of genotypes is essential to get an idea about suitable parents to be selected in breeding programmes and to identify desirable cross combinations to be released as hybrid. Hence, present experiment was conducted to estimate the combining ability effects in castor for seed yield and component traits.

Materials and Methods

In the present experiment 44 entries were evaluated *i.e.* 3 lines and 10 testers and their resulting 30 hybrids developed by line x tester mating design along with one hybrid check variety GCH-8. These 44 entries were planted in randomized block design (RBD) with three replications in three environmental conditions *i.e.* E1: Kharif, 2020 at ARS, Mandor, Jodhpur; E2: Kharif, 2021 at ARS, Mandor, Jodhpur and E3: Late Kharif 2021 at Instructional Farm, College of Agriculture, Jodhpur. The crop in E_1 was sown on 1st week of August and E_2 on 4th week of August and E_3 on 2nd week of September. The details of parental lines are given in Table 1 and mean sum of squares are presented in Table 2.

Observations were recorded for ten characters *viz.,* number of effective raceme per plant (NERP), effective primary raceme length (cm) (EPRL), number of capsules per primary raceme (NCPR); 100-seed weight (g) (SW), seed yield at 120 days after sowing (g plant^{-1}) (SY120), seed yield at 150 days after sowing (g plant^{-1}) (SY150), seed yield at 180 days after sowing (g plant^{-1}) (SY180), seed yield at 210 days after

Table 2. ANOVA for mean sum of square of 10 castor traits for pooled environment

Source of variance	d.f.	NERP	EPRL	NCPR	SW	SY120
Environment	2	1722.90**	182.48**	60865.41**	305.27**	127583.00**
Replication × Environment	4	1.58	65.72	56.56	5.53	18.88
Genotype × environment	84	40.16**	157.76**	923.91**	8.12	2273.98**
Parents × Environment	24	45.57**	137.98**	468.69**	12.75**	1468.91**
Line × Environment	4	34.94**	242.00**	461.02**	9.39	2961.83**
Tester × Environment	18	30.83**	93.90**	450.55**	12.65*	1236.01**
Parents (Line *vs.* Tester) × Environment	2	199.54**	326.64**	647.35**	20.33*	579.17
Parents *vs.* Hybrid × Environment	2	154.90**	664.86**	1907.20**	31.90**	4298.41**
Hybrid × Environment	58	33.96**	148.46**	1078.37**	5.39	2537.30**
Pooled Error	252	1.89	30.67	62.09	6.47	198.18
Total	386	28.85	207.28	1060.04	11.79	2228.67
Source of variance	d.f.	SY150	SY180	SY210	OC	RAC
Environment	2	295236.70**	178422.50**	127015.30**	615.44**	550.42**
Replication × Environment	4	1017.87	2375.72	2631.89	8.32	12.59
Genotype × environment	84	7554.72**	7738.55**	7665.04**	9.10**	10.07*
Parents × Environment	24	10139.37**	10426.13**	10550.37**	7.76*	7.22
Line × Environment	4	7527.66**	9930.97**	8013.32*	15.15*	15.99
Tester × Environment	18	10725.57**	10639.21**	11084.60**	6.60	6.07
Parents (Line *vs.* Tester) × Environment	2	10087.00**	9498.67**	10816.35*	3.48	0.10
Parents *vs.* Hybrid × Environment	2	2841.77**	4186.08*	534.43	2.75	0.25
Hybrid × Environment	58	6647.73**	6748.94**	6717.00**	9.87**	11.58**
Pooled Error	252	602.48	1261.68	2461.97	4.68	6.99
Total	386	4986.83	5039.12	5530.38	10.13	11.18

d.f.= degree of freedom; *,**= Significant at 5% and 1%, respectively

sowing (g plant^{-1}) (SY210); oil content (%) (OC), ricinoleic acid content (%) (RAC). Combining ability analysis for these traits was performed as per procedure developed by Kempthorne (1957) using Windostat version 9.3.

Results and Discussion

All the traits except oil content and ricinoleic acid content showed positive effect on seed yield as higher number of effective raceme per plant along with long panicle and maximum number of capsules as well as higher 100-seed weight contributed to total seed yield. Therefore, significant positive gca and sca effects are considered desirable. High oil content and ricinoleic acid content are also of great importance because of high industrial demand as these possess many pharmaceutical and medicinal properties. Analysis of variance for combining ability indicated that gca interaction for female x environment were significant for all the traits except number of effective raceme per plant, 100-seed weight and ricinoleic acid content determined that gca variances were much influenced by environments, whereas for male x environment none of the traits showed significance (Table 3). In contrast, the sca variance (line x tester effect) x environment was significant for all the characters studied except for 100-seed weight, oil content and ricinoleic acid content indicating that estimates of sca variances were highly influenced by the environments. The magnitude of σ^2gca was greater than σ^2sca for effective primary raceme length and 100-seed weight over environments indicating preponderance of additive gene action in the expression of these characters. Predominant role of additive gene action in the inheritance of various characters were also observed by several researchers like Tank *et al.* (2003), Chandramohan *et al.* (2006), Ramesh *et al.* (2013), Delvadiya *et al.* (2018), Kajal *et al.* (2021) and Mohanty *et al.* (2021) in castor genotypes. The estimates of σ^2sca were greater than σ^2gca for volume weight indicating that the trait was predominantly under the control of non-additive gene action. Predominance of non-additive gene action has been reported

Table 3. Analysis of variance of combining ability for various characters in castor genotypes

Source of Variations	d.f.	NERP	EPRL	NCPR	SW	SY120
Environment	2	1652.09**	18.86	50195.47**	312.26**	111673.30**
Replication × Environment	4	3.59	49.12	74.42	3.15	9.27
Line effect × Environment	4	36.46	323.40*	4674.77**	5.77	8198.67**
Tester effect × Environment	18	41.33	177.21	766.72	6.26	2284.62
(Line × Tester effect) × Environment	36	30.00**	114.64**	834.60**	4.91	2034.59**
Pooled error	174	1.94	31.89	66.49	6.11	223.85
σ^2gca		2.01	117.00	205.47	1.23	215.22
σ^2sca		2.55	19.57	214.40	0.25	345.40
σ^2gca/ σ^2sca		0.79	5.98	0.96	4.92	0.62
Source of Variations	d.f.	SY150	SY180	SY210	OC	RAC
Environment	2	180352.40**	134961.70**	81860.54**	428.74**	387.65**
Replication × Environment	4	981.19	2054.70	3521.99	6.53	26.70*
Line effect × Environment	4	34268.82**	34073.55**	30999.92**	28.30**	18.95
Tester effect × Environment	18	3199.76	3128.00	3428.27	11.24	15.16
(Line × Tester effect) × Environment	36	5302.70**	5523.35**	5663.26**	7.13	8.97
Pooled error	174	662.72	1230.97	2051.03	5.03	8.16
σ^2gca		555.21	707.41	713.32	0.16	0.02
σ^2sca		1086.11	1088.17	1022.20	-0.04	-0.20
σ^2gca/ σ^2sca		0.51	0.65	0.70	-4.00	-0.10

d.f.= degree of freedom, σ^2gca= variance due to general combining ability, σ^2sca= variance due to specific combining ability; *,**= Significant at 5% and 1%, respectively

earlier by Pathak *et al.* (1989) for seed yield and; Patel *et al.* (2017) for volume weight. Environmental influence was reported for oil content and ricinoleic acid content as the ratio of variance due to gca to variance due to sca (σ^2gca/σ^2sca) was negative (Harriman and Nwammadu, 2016).

General combining ability effects indicated that among lines, MCP-1-1 is good general combiner for seed yield at 120, 150, 180 and 210 days after sowing and; two testers *viz.*, MP-12-17 and MP-27-17 are superior for overall seed yield at final harvest (at 210 days after sowing) and also for some yield governing traits (Table 4). High gca effects for seed yield were also observed by Ramesh *et al.* (2013), Patel *et al.* (2017), Panera *et al.* (2018) and Ramesh *et al.* (2021) in their findings. For both high oil content and ricinoleic acid content MP-36-17 was considered as desirable.

MP-36-17 and MP-32-17 were considered desirable for high oil content; and MP-36-17 was the only tester, possessing high gca for ricinoleic acid content, which is desirable for getting high quality seeds. For high oil content current findings are in agreement with the previous observations made by researchers like Patel *et al.* (2017) and Ramesh *et al.* (2021).

Hybrids possessing high sca effects for overall seed yield and other related traits were SKP-84 × MP-36-17, MCP-1-1 × MP-12-17 and DPC-15 × MP-34-17. Significant sca effect for seed yield was also observed by Solanki and Joshi (2000), Kanwal *et al.* (2006), Barad *et al.* (2009), Kasture *et al.* (2014), Patel *et al.* (2015), Jalu *et al.* (2017), Panera *et al.* (2018) and Mohanty *et al.* (2021). On the basis of Table 5, showing top three general (lines and testers) and specific combiners none of the hybrids were considered as the best specific combiner for oil content and ricinoleic acid content in individual environment as well as in pooled environment.

Finally it is concluded that, the corresponding good combiner parents can further be exploited in breeding programs for getting desirable cross combinations and their better cross combinations with high sca effects considered to be the best among all hybrids for further evaluatrion and can be utilized for yield advancement in castor in arid and semi-arid regions of Rajasthan.

Table 4. General and specific combining ability effects for various traits in castor over pooled environments

Genotypes	NERP	EPRL	NCPR	SW	SY120	SY150	SY180	SY210	OC	RAC
Lines										
MCP-1-1	-0.06	5.49**	6.60**	-0.35	16.65**	20.52**	27.44**	26.67**	0.17	-0.17
SKP-84	-0.56**	8.29**	8.17**	0.95**	-5.35**	7.88**	3.23	5.36	0.16	0.15
DPC-15	0.63**	-13.78**	-14.77**	-0.60*	-11.30**	-28.40**	-30.67**	-32.02**	-0.33	0.03
Testers										
MP-2-17	-3.42**	4.42**	12.51**	-0.78	0.02	-4.09	-2.73	-1.90	-0.72	-0.55
MP-12-17	4.95**	-2.12	-20.43**	0.53	-6.10*	23.16**	22.88**	24.26**	0.69	0.51
MP-27-17	-1.47**	9.76**	24.53**	-1.33**	-0.07	24.01**	26.71**	20.99*	-0.12	-0.12
MP-32-17	-1.95**	2.14	14.96**	0.79	6.68*	13.77**	12.32	12.75	0.92*	-0.10
MP-34-17	-2.60**	-5.78**	-15.28**	-1.54**	-12.7**	-18.81**	-20.71**	-17.05	-0.88*	-0.74
MP-35-17	0.32	4.60**	24.36**	-1.27**	27.92**	-16.25**	-13.96*	-11.66	0.56	1.06
MP-36-17	3.26**	-7.98**	-21.98**	4.31**	15.28**	-7.13	-4.69	-7.06	1.13**	1.15*
MP-39-17	2.61**	-3.40**	-20.55**	-1.68**	-27.38**	-21.03**	-19.66**	-26.60**	-1.36**	-1.13*
MP-41-17	-0.13	-0.32	1.58	-0.54	-5.23	-9.01	-14.50*	-9.28	0.57	0.41
MP-42-17	-1.57**	-1.34	0.30	1.52**	1.63	15.37**	14.34*	15.56	-0.80	-0.48
S.E. (gi)	0.21	0.84	1.22	0.37	2.23	3.84	5.23	6.75	0.33	0.43
S.E. (gj)	0.38	1.54	2.22	0.67	4.07	7.01	9.55	12.33	0.61	0.78
MCP-1-1 x MP-2-17	2.94**	1.02	-10.66**	0.38	5.98	24.49**	28.88*	21.87	-0.71	-0.07
MCP-1-1 x MP-12-17	0.27	2.48	10.08**	-1.01	-8.46	39.55**	43.92**	50.23**	1.05	1.05
MCP-1-1 x MP-27-17	-1.05*	-0.30	-11.87*	0.89	40.60**	-19.15*	-15.72	-16.15	1.09	1.09
MCP-1-1 x MP-32-17	0.62	-5.95**	-2.75	-0.46	3.34	13.45	20.92	14.32	0.49	-1.80
MCP-1-1 x MP-34-17	-0.97*	0.69	-9.18**	0.17	-8.07	-7.33	-10.73	-6.16	-0.80	0.00
MCP-1-1 x MP-35-17	-0.15	-3.10	15.45**	-0.61	5.96	24.48**	27.39*	18.92	0.11	-0.19
MCP-1-1 x MP-36-17	-1.44**	-1.43	-6.72*	-0.68	-14.17**	-62.71**	-59.95**	-63.64**	-0.51	-0.07
MCP-1-1 x MP-39-17	-0.42	-0.87	6.24*	-0.98	4.05	8.93	11.10	11.88	-0.13	0.29
MCP-1-1 x MP-41-17	-0.46	5.51**	18.48**	1.70*	-20.53**	-34.38**	-46.93**	-47.21**	-0.27	-0.18
MCP-1-1 x MP-42-17	0.64	1.96	-9.07**	0.58	-8.70	12.67	1.12	15.93	-0.31	-0.12
SKP-84 x MP-2-17	-0.60	-3.89*	2.66	0.55	-9.33	-27.21**	-28.23*	-26.99	0.59	0.50
SKP-84 x MP-12-17	-0.60	0.58	-10.66**	-0.58	2.41	-8.38	-12.03	-11.36	-0.03	0.05
SKP-84 x MP-27-17	-0.88	-8.78**	-12.96**	0.23	-19.83**	0.25	1.86	2.16	-1.04	-1.17
SKP-84 x MP-32-17	-1.44**	1.23	-14.18**	-0.01	-8.93	8.47	1.56	3.07	-0.50	0.55
SKP-84 x MP-34-17	0.47	2.89	18.17**	0.20	7.38	-28.12**	-25.71*	-33.66*	0.25	-0.15
SKP-84 x MP-35-17	-0.96*	4.50*	2.92	0.24	18.88**	-23.75**	-25.66*	-9.26	-0.10	-0.38
SKP-84 x MP-36-17	3.34**	1.07	3.66	0.66	19.55**	62.88**	60.82**	54.22**	-0.18	-0.27
SKP-84 x MP-39-17	-0.66	-0.01	-3.06	0.79	4.65	-24.44**	-23.23*	-25.36	0.68	0.45
SKP-84 x MP-41-17	1.41**	1.90	-0.45	-1.38	-13.89**	20.55*	29.48*	35.13*	0.59	0.60
SKP-84 x MP-42-17	-0.08	0.51	13.90**	-0.71	-0.89	19.75*	21.14	12.04	-0.27	-0.17
DPC-15 x MP-2-17	-2.34**	2.87	8.00**	-0.93	3.34	2.72	-0.65	5.12	0.13	-0.43
DPC-15 x MP-12-17	0.33	-3.05	0.58	1.59	6.04	-31.17**	-31.89**	-38.87*	-1.02	-1.09
DPC-15 x MP-27-17	1.93**	9.08**	24.83**	-1.12	-20.77**	18.90*	13.86	13.98	-0.05	0.09
DPC-15 x MP-32-17	0.82	4.71*	16.93**	0.46	5.59	-21.92*	-22.48	-17.39	0.02	1.25
DPC-15 x MP-34-17	0.50	-3.58	-9.00**	-0.38	0.70	35.44**	36.44**	39.82**	0.55	0.15
DPC-15 x MP-35-17	1.11*	-1.41	-18.36**	0.37	-24.84**	-0.73	-1.74	-9.67	0.00	0.57
DPC-15 x MP-36-17	-1.90**	0.36	3.05	0.02	-5.38	-0.17	-0.86	9.42	0.68	0.35
DPC-15 x MP-39-17	1.08*	0.89	-3.18	0.18	-8.70	15.51	12.13	13.48	-0.55	-0.74
DPC-15 x MP-41-17	-0.96*	-7.41**	-18.03**	-0.33	34.42**	13.83	17.45	12.08	-0.33	-0.42
DPC-15 x MP-42.17	-0.56	-2.46	-4.83	0.13	9.59	-32.42**	-22.27	-27.97	0.58	0.29
S.E. (Sij)	0.66	2.66	3.84	1.17	7.05	12.14	16.54	21.35	1.06	1.35

Table 5. Top general and specific combiners over pooled environment

Traits	General combiners		Specific combiners
Effective raceme per plant	DPC-15	MP-12-17	SKP-84 × MP-36-17
	-	MP-36-17	MCP-1-1 × MP-2-17
	-	MP-39-17	DPC-15 × MP-27-17
Effective primary raceme length (cm)	SKP-84	MP-27-17	DPC-15 × MP-27-17
	MCP-1-1	MP-35-17	MCP-1-1 × MP-41-17
	-	MP-2-17	DPC-15 × MP-32-17
Number of capsules per primary raceme	SKP-84	MP-27-17	DPC-15 × MP27-17
	MCP-1-1	MP-35-17	MCP-1-1 × MP-41-17
	-	MP-32-17	SKP-84 × MP-34-17
100-seed weight (g)	SKP-84	MP-36-17	MCP-1-1 × MP-41-17
	-	MP-42-17	-
Seed yield at 120 days after sowing (g $plant^{-1}$)	MCP-1-1	MP-35-17	MCP-1-1 × MP-27-17
	-	MP-36-17	DPC-15 × MP-41-17
	-	MP-32-17	SKP-84 × MP-36-17
Seed yield at 150 days after sowing (g $plant^{-1}$)	MCP-1-1	MP-27-17	SKP-84 × MP-36-17
	SKP-84	MP-12-17	MCP-1-1 × MP-12-17
	-	MP-42-17	DPC-15 × MP-34-17
Seed yield at 180 days after sowing (g $plant^{-1}$)	MCP-1-1	MP-27-17	SKP-84 × MP-36-17
	-	MP-12-17	MCP-1-1 × MP-12-17
	-	MP-42-17	DPC-15 × MP-34-17
Seed yield at 210 days after sowing (g $plant^{-1}$)	MCP-1-1	MP-12-17	SKP-84 × MP-36-17
	-	MP-27-17	MCP-1-1 × MP-12-17
	-	-	DPC-15 × MP-34-17
Oil content (%)	-	MP-36-17	-
	-	MP-32-17	-
Ricinoleic acid content (%)	-	MP-36-17	-

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