Combining Ability Analysis for Seed Yield per Plant and its Contributing Traits in Castor (*Ricinus communis* L.)

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Abstract— *A line × tester analysis of twenty four hybrids developed by crossing four lines and six testers were carried out under three diverse environments. The components of genetic variance were estimated from the analysis of variances for combining ability of different characters for each environment and pooled also. The analysis of variance for combining ability individual as well as pooled over environments revealed that mean squares due to lines and testers were significant for most the characters, Line × Tester was significant for all the characters except seed yield per plant and estimated genetic variance due to GCA and SCA was non-significant for all the characters in pooled over environments. The ratio of σ^2gca/σ^2sca was less than unity which revealed the predominant role of non-additive gene action for inheritance of the traits for days to flowering, days to maturity, number of nodes up to primary raceme, effective length of primary raceme, seed yield per plant and 100-seed weight. Therefore, heterosis breeding may be suggested to exploit hybrid vigour and recombinant in F_2 and subsequent generations for isolating lines for seed yield and its contributing traits. The line SKP 126 and tester SKI 420 were found as good general combiners for the yield attributing characters in pooled over the environments. Among the crosses, best three specific combiner were SKP 120 × SKI 420, SKP 126 × SKI 357 and SKP 106 × SKI 412 for seed yield per plant and its contributing traits.*

Keywords— Combining ability, Gene action, GCA, SCA.

I. INTRODUCTION

Castor (*Ricinus communis* L.), a monotypic species in the spurge family (Euphorbiaceae) with 2n = 20 chromosomes, is an important non-edible oilseed crop. India is one of the largest producers of non-edible oilseeds in the world. It is also known as the castor-oil plant, higuerito, higuerillo, palma, christi, carrapateira and many other common names i.e. arindi, divela. In mature castor seed, 90-95% of the total seed protein is in the endosperm. In the endosperm, crystalloid proteins comprise 70 to 80% of the total protein and are insoluble in water. It has the approximate fatty acid composition of ricinoleic acid (87%), oleic acid (7%), linoleic acid (3%), palmitic acid (2%) and stearic acid (1%), with trace amounts of dihydroxystearic acid. Ricinoleic acid available in castor bean oil has its proven effectiveness in inhibiting the growth of various species of viruses, bacteria, yeasts and moulds. Ricin, a poisonous substance found in castor, is state-of-art tool in neurobiology for selectively destroying neuronal populations (De-La-Cruz *et al*., 1995).

The combining ability helps in partitioning the total genetic variation into general combining ability of parents and specific combining ability of crosses, which is useful to assess the nature and magnitude of gene action controlling different characters. The efficient partitioning of genetic variance into its components *viz.*, additive and non-additive will help in formulating an effective and sound breeding programme. The cases where the cost of hybrid seed are of greater importance, the use of additive gene effects of parents could be used to retain the vigour in subsequent segregating generations to develop stable varieties, while non-additive gene effects respond to heterosis breeding. Among the several methods, Line x Tester analysis of combining ability is one of the important biometrical tools to identify the promising male and female parental lines as well as to obtain necessary data on the expression of heterosis for the future. Line x Tester analysis provides information for combining ability. The study of general combining ability (GCA) effects help in selection of superior parents and specific combining ability (SCA) effects for superior hybrids. With the help of this information it gives overall genetic pictures of the materials under investigation.

II. MATERIALS AND METHODS

The present investigation was carried out using Line × Tester design for ten characters at three locations during *kharif* 2023 to generate information on combining ability and for seed yield and its components traits. The experimental materials consisted of 35 genotypes; comprising of 24 hybrids developed by using Line × Tester design, 4 lines and 6 testers, with standard check hybrid GCH 8. All the genotypes were evaluated in Randomized Block Design (RBD) replicated thrice in three environments formed by different locations and observations were recorded on ten characters *viz.*, Days to flowering, Days to maturity, Plant height up to primary raceme (cm), Number of nodes up to primary raceme, Effective length of primary raceme (cm), Number of capsules on primary raceme, Effective branches per plant, Seed yield per plant (g), 100-seed weight (g) and Oil content (%). The mean values on these ten characters were recorded in all the three locations of experimentation and the pooled mean values were subjected to statistical analysis.

III. RESULTS AND DISCUSSIONS

The analysis of variance for combining ability carried out for ten characters under investigation is presented in Table.1 for pooled over three environments. The analysis of variance for combing ability revealed that variations due to lines used as females were significant for all characters.

TABLE 1
ANALYSIS OF VARIANCE FOR COMBINING ABILITY, ESTIMATES OF COMPONENTS OF VARIANCE AND THEIR RATIOS FOR DIFFERENT CHARACTERS IN CASTOR FOR POOLED OVER THREE ENVIRONMENTS

Source of variation	d. f.	Days to flowering	Days to maturity	Plant height up to primary raceme	Number of nodes up to primary raceme	Effective length of primary raceme
Environments	2	1051.27 **	2624.48 **	4410.62 **	87.24 **	363.15 **
Replications	2	7.48	35.93 *	107.33	7.82	91.61
Line (L)	3	45.66 **	113.14 **	3489.68 **	53.97 **	1276.47 **
Tester (T)	5	78.29 **	128.39 **	3689.87 **	38.39 **	74.18
Line × Tester	1	318.94 **	818.94 **	32978.52 **	311.15 **	998.51 **
Line × Environment	6	1.52	6.78	24.43	8.66 **	170.26 **
Tester × Environment	10	7.13 *	9.33	41.2	0.48	75.61 *
L × T × Environment	2	7.03	3.56	235.11 *	6.48	151.23 *
σ^2gca	-	1.68	2.9	66.4	0.06	26.97
σ^2sca	-	2.97	6.2	30.36	0.12	40.48
σ^2gca/ σ^2sca	-	0.57	0.47	2.19	0.47	0.67
Pooled Error	138	3.41	8.87	75.8	2.67	40.48

TABLE 1 CONTINUE

Source of variation	d. f.	Number of capsules on primary raceme	Effective branches per plant	Seed yield per plant	100-seed weight	Oil content
Environments	2	485.40 **	131.88 **	11472.38 **	57.04 **	3.33 *
Replications	2	33.13	5.27 *	2709.54	0.52	1.72
Line (L)	3	939.25 **	18.86 **	10086.16 **	27.24 **	4.77 **
Tester (T)	5	247.54 **	46.22 **	3512.69	82.58 **	57.19 **
Line × Tester	1	4135.61 **	21.84 **	439.56	133.98 **	65.94 **
Line × Environment	6	86.29	2.94 *	1971.19	2.23	0.18
Tester × Environment	10	172.90 **	3.15 **	232.68	2.62 *	0.15
L × T × Environment	2	300.73 *	12.21 **	90.5	3.61 *	0.02
σ^2gca	-	22.81	3.38	2266.05	0.8	1.52
σ^2sca	-	17.23	1.64	2643.44	1.41	1.27
σ^2gca/ σ^2sca	-	1.32	2.06	0.86	0.56	1.19
Pooled Error	138	69.89	1.45	1656.91	1.21	0.51

,** Significant at $P \leq 0.05$ and $P \leq 0.01$ levels of probability, respectively

The variations due to testers mean square were significant for all the traits except effective length of primary raceme and seed yield per plant. The analysis of variance for combing ability also revealed that variations due to line × tester were significant for all the traits (except for seed yield per plant). This data suggested the importance of gene action in the inheritance of traits under investigation. The line × environment interaction variance was found to be significant for number of nodes up to primary raceme, effective length of primary raceme and effective branches per plant. Similarly, testers responded differently to array of the environments as the variance due to testers × environments interaction was significant for most of the characters like days to flowering, effective length of primary raceme, number of capsules on primary raceme, effective branches per plant and 100 seed weight.

Significance of hybrids × environments interaction variance revealed that performance of hybrids varied over the environments for the trait under study except days to flowering, days to maturity, number of nodes up to primary raceme, seed yield per plant and oil content. Genetic variance due to gca (σ^2gca) and sca (σ^2sca) was non-significant for all the characters in pooled over environments. The ratio of σ^2gca/σ^2sca was greater than unity which revealed the predominant role of additive gene action for inheritance of the traits in pooled over environments for plant height up to primary raceme, number of capsules on primary raceme, effective branches per plant and oil content. The ratio of σ^2gca/σ^2sca was less than unity which revealed the predominant role of non-additive gene action for inheritance of most of the traits in pooled over environments for days to flowering, days to maturity, number of nodes up to primary raceme, effective length of primary raceme, seed yield per plant and 100 seed weight.

The similar results for ratio of σ^2gca/σ^2sca, for additive gene action were reported by Rajani *et al.* (2015), Sapovadiya *et al.* (2015b), kavani *et al.* (2016), Delvadiya *et al.* (2018), Panera *et al.* (2018) and Mohanty *et al.* (2021). For non-additive gene action different traits of castor under study showed similar results as reported by Ramesh *et al.* (2013), Rajani *et al.* (2015), Sapovadiya *et al.* (2015b), Delvadiya *et al.* (2018), Dube *et al.* (2018), Panera *et al.* (2018) and Ramya *et al.* (2018).

TABLE 2
ESTIMATES OF GENERAL COMBINING ABILITY EFFECTS OF LINES AND TESTERS IN POOLED OVER ENVIRONMENT

Sr. No.	Parents	DF	DM	PH	NN	LP	NC	EB	SY	SW	OC
Lines											
1	SKP 84	0.14	0.54	-4.53 **	-0.15	-0.13	0.11	-2.44 **	12.88 *	1.00 **	-0.56 **
2	SKP 106	-0.06	0.57	0.91	0.27	2.66 **	1.65	0.13	22.31 **	-1.12 **	0.54 **
3	SKP 120	-1.15 **	-1.87 **	-3.95 **	-0.36	-8.31 **	-6.86 **	0.09	-74.53 **	0.06	0.39 **
4	SKP 126	1.07 **	0.76	7.58 **	0.24	5.78 **	5.10 **	2.23 **	39.35 **	0.06	-0.36 **
S. Em. ±		0.25	0.41	1.18	0.22	0.87	1.14	0.16	5.54	0.15	0.09
Testers											
1	JC 12	2.86 **	3.66 **	-7.78 **	0.24	-4.08 **	-6.05 **	-2.06 **	-13.23	1.75 **	1.52 **
2	SKI 357	-2.01 **	-2.26 **	-12.01 **	-0.55 *	-3.50 **	-2.84 *	0.38	-24.25 **	-1.20 **	-1.34 **
3	SKI 403	-1.09 **	0.13	8.20 **	-0.22	-0.27	-0.61	-0.13	-48.33 **	-0.09	-2.10 **
4	SKI 407	-0.73 *	-2.76 **	17.89 **	0.39	1.23	0.29	-1.06 **	-4.99	-0.29	-0.99 **
5	SKI 412	-0.34	0.41	-1.86	0.35	-0.01	0.90	-0.25	12.80	-0.18	2.71 **
6	SKI 420	1.30 **	0.82	-4.44 **	-0.21	6.63 **	8.31 **	3.11 **	77.99 **	0.00	0.19
S. Em. ±		0.31	0.50	1.45	0.27	1.06	1.39	0.20	6.78	0.18	0.12

***, ** Significant at P ≤ 0.05 and P ≤ 0.01 levels of probability, respectively**
DF – Days to flowering, DM – Days to maturity, PH – Plant height upto primary raceme, NN – Number of nodes upto primary raceme, LP – Effective length of primary raceme, NC – Number of capsules on primary raceme, EB – Effective branches, SY – Seed yield per plant, SW – 100 seed weight, OC – Oil content

The estimate of GCA effect indicated that the parents SKP 120 and testers SKI 357 were good general combiners for earliness (Table 2) i.e. for days to flowering, days to maturity, plant height upto primary raceme and number of nodes up to primary raceme. Good general combiners for these traits were also reported by Mohanty *et al*. (2021). Parental lines SKP 126 and SKI 420 were good combiners for effective length of primary raceme and number of capsules on primary raceme and effective branches per plant. On pooled over environments basis the line SKP 84, SKP 106 and SKP 126, where tester SKI 420 were recorded to have significantly positive gca effects for the trait. The results were in correspondence to Panera *et al.* (2018), Delvadiya *et al*. (2018) and Yamanura *et al*. (2020). The line SKP 84 and testers JC 12 were found to have significant positive gca effects for the 100 seed weight. Where, for oil content lines SKP 106 and SKP 120 and testers JC 12 and SKI 412 were found to have significant positive gca effects (Table 2). Similar kind of research were also found by Kavani *et al*. (2016) and Ramya *et al*. (2018).

Hybrids SKP 84 × JC 12, SKP 106 × SKI 412 and SKP 120 × SKI 357, SKP 120 × SKI 403 were found significant negative sca for days to flowering and days to maturity (Table 3). For days to flowering and days to maturity Sridhar *et al.* (2008) and Yamunura *et al*. (2020) also reported the same results for hybrids they studied. SKP 120 × SKI 412, SKP 126 × SKI 403 and SKP 106 × SKI 420 found negative significant sca effect in pooled over environments. Out of total twenty four hybrids, two hybrids SKP 120 × SKI 420 and SKP 84 × JC 12 found positive significant sca effect in pooled over environments for effective length of primary raceme and number of capsules up to primary raceme (Table 3). For effective branches per plant and seed yield per plant, four hybrids *viz.*, SKP 120 × SKI 420, SKP 126 × SKI 357, SKP 84 × SKI 412 and SKP 106 × SKI 412 found positive significant sca effect in pooled over environments. Three hybrids exhibiting highest positive significant sca effect for oil content were SKP 120 × SKI 407, SKP 126 × JC 12 and SKP 126 × SKI 412 (Table 3).

TABLE 3
ESTIMATES OF SPECIFIC COMBINING ABILITY EFFECTS OF HYBRIDS IN POOLED OVER ENVIRONMENTS

Sr. No.	Hybrids	DF	DM	PH	NN	LP	NC	EB	SY	SW	OC
1	SKP 84 × JC 12	-2.12 **	-2.84 **	0.03	0.38	7.11 **	5.69 *	0.50	13.60	0.35	0.30
2	SKP 84 × SKI 357	-0.14	1.52	-5.17	-0.14	5.32 *	5.07	-0.64	-11.22	-0.97 **	-0.61 *
3	SKP 84 × SKI 403	1.38 *	2.24 *	-1.05	0.11	-6.23 **	-2.65	-1.11 **	14.00	-0.22	-0.14
4	SKP 84 × SKI 407	-0.76	-0.87	3.01	-0.91	-1.15	-3.23	0.59	17.29	1.59 **	-1.10 **
5	SKP 84 × SKI 412	0.41	1.41	2.65	1.21 *	-4.05	-3.66	2.25 **	30.94 *	0.32	0.74 **
6	SKP 84 × SKI 420	1.22 *	-1.45	0.53	-0.63	-1.00	-1.21	-1.60 **	-64.62 **	-1.09 **	0.82 **
7	SKP 106 × JC 12	0.42	-0.66	7.78 **	0.06	2.49	2.23	1.23 **	38.29 **	0.37	-1.06 **
8	SKP 106 × SKI 357	2.51 **	3.26 **	6.04 *	0.26	-2.80	-3.00	0.10	-58.59 **	-0.51	0.99 **
9	SKP 106 × SKI 403	1.14	2.20 *	0.15	0.54	0.03	1.75	-0.44	-56.72 **	0.49	0.58 *
10	SKP 106 × SKI 407	-0.55	-1.13	-2.29	-0.11	7.41 **	5.05	-1.52 **	25.92	-3.09 **	-0.02
11	SKP 106 × SKI 412	-1.94 **	-3.41 **	-5.46	-0.96	4.74 *	1.96	0.37	51.66 **	1.53 **	0.04
12	SKP 106 × SKI 420	-1.58 *	-0.27	-6.22 *	0.22	-11.87 **	-7.99 **	0.26	-0.57	1.21 **	-0.52 *
13	SKP 120 × JC 12	2.63 **	2.45 *	-5.67	0.37	-11.67 **	-8.81 **	-1.42 **	-55.67 **	-0.43	-0.63 **
14	SKP 120 × SKI 357	-1.18	-3.85 **	0.35	-0.43	0.53	-0.85	-0.65	3.37	0.68	-0.27
15	SKP 120 × SKI 403	-2.10 **	-3.57 **	7.22 *	-0.52	4.26	0.47	0.83 *	38.83 **	-0.23	0.07
16	SKP 120 × SKI 407	1.54 *	3.76 **	-1.83	0.48	-1.66	2.99	1.37 **	-16.34	0.85 *	2.34 **
17	SKP 120 × SKI 412	-1.29 *	0.15	-7.70 **	-0.13	-1.41	-0.82	-1.58 **	-66.63 **	-0.95 *	-1.79 **
18	SKP 120 × SKI 420	0.40	1.07	7.63 **	0.23	9.95 **	7.03 *	1.44 **	96.43 **	0.09	0.28
19	SKP 126 × JC 12	-0.93	1.05	-2.15	-0.80	2.07	0.90	-0.32	3.78	-0.29	1.39 **
20	SKP 126 × SKI 357	-1.18	-0.93	-1.22	0.32	-3.05	-1.21	1.19 **	66.43 **	0.80 *	-0.11
21	SKP 126 × SKI 403	-0.43	-0.87	-6.32 *	-0.12	1.95	0.43	0.72	3.89	-0.04	-0.50 *
22	SKP 126 × SKI 407	-0.24	-1.76	1.11	0.55	-4.61 *	-4.81	-0.44	-26.88 *	0.64	-1.22 **
23	SKP 126 × SKI 412	2.82 **	1.85	10.51 **	-0.12	0.71	2.52	-1.05 **	-15.96	-0.90 *	1.01 **
24	SKP 126 × SKI 420	-0.04	0.66	-1.95	0.18	2.91	2.18	-0.10	-31.25 *	-0.21	-0.58 *

IV. CONCLUSION

The estimates of genetic variance revealed preponderance of non-additive gene action for inheritance of days to flowering, days to maturity, number of nodes up to primary raceme, effective length of primary raceme, number of capsules on primary raceme, seed yield per plant and 100 seed weight. Therefore, population improvement by advancing hybrids involved in both good general combiner parents may be followed along with heterosis breeding; thus, superior recombinants may be isolated for future breeding programmes. The lines SKP 126 and tester SKI 420 were found as good general combiners for the yield-attributing characters in pooled over the environments. Therefore, these parents would be of immense value for the simultaneous improvement of desirable agronomical/morphological attributes in addition to heterosis breeding. Among the crosses, the best three specific combiner hybrids were SKP 120 × SKI 420, SKP 126 × SKI 357 and SKP 106 × SKI 412 for seed yield per plant. They also exhibited significant and desirable SCA effects for other component characters, justifying seed yield phenomena as a dependent complex character and is the outcome of direct and indirect effects of different component characters.

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