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VA Kulkarni
Department of Genetics and Plant Breeding, COA, Latur, Maharashtra, India

PB Wadikar
Associate Professor, Department of Genetics and Plant Breeding, COA, Latur, Maharashtra, India

DD Latthe
Department of Genetics and Plant Breeding, COA, Latur, Maharashtra, India

AR Jadhav
Department of Genetics and Plant Breeding, COA, Latur, Maharashtra, India

AA Shaikh
Department of Genetics and Plant Breeding, COA, Latur, Maharashtra, India

Corresponding Author:
VA Kulkarni
Department of Genetics and Plant Breeding, COA, Latur, Maharashtra, India

Study on the effect of combining ability and gene action on yield and its contributing traits in Linseed (*Linum usitatissimum* L.)

VA Kulkarni, PB Wadikar, DD Latthe, AR Jadhav and AA Shaikh

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Abstract
A line x tester analysis using six lines and four testers was carried out to study the combining ability and gene action for seed yield and its related characters in linseed (*Linum usitatissimum* L.). Analysis of variance for combining ability revealed a significant difference among the mean squares for lines, testers and crosses for all the traits except the character number of branches per plant which indicated that there was enough variation present in the experimental material. Among the lines, ES-1445 and EC-41741 were the best general combiners for seed yield and its contributing traits. Among the testers, EI-5511 manifested the highest significant GCA effect for seed yield and its attributing characters. These genotypes can be utilized in the breeding programme as parents for the development of superior hybrids. A significantly positive SCA effect for seed yield per plant was reported by the crosses, GS-105 x EI-5511, FR-111 x LSL-93, JLS-395 x GS-09 and EC-41741 x RLC-04. These crosses can be exploited for heterosis breeding by checking their *per se* performance for seed yield. The ratio of GCA and SCA revealed that there is a preponderance of non-additive gene action for yield influencing characters such as number of branches per plant, number of capsules per plant, number of seeds per capsule, harvest index (%) and seed yield per plant (g) and exploitation of heterosis is beneficial for such characters.

Keywords: Linseed, GCA, SCA, line x tester, gene action

Introduction

The most economically significant industrial non-food crop and the earliest domesticated edible oilseed crop, linseed (*Linum usitatissimum* L.) is an annual self-pollinated diploid (2n = 30) oilseed crop that has been cultivated for millennia for both its fiber and seeds. It is cultivated mainly for its essential polyunsaturated fatty acids, such as alpha-linolenic acid and its abundant amounts of soluble dietary fiber. It is also known as "Alsi" or "Tisi". Flax fiber and seed oil (linseed) or both (dual-purpose linseed) are other reasons it is grown. Flax seed oil is utilized as an industrial drying oil due to its high linolenic acid concentration. Because they reduce blood triglyceride levels, which in turn lessen heart disease, omega-3 fatty acids have been demonstrated to be useful in the treatment of inflammatory illnesses including heart disease. (Mishra *et al*. 2013) [5].

Furthermore, cakes made from linseed oil are an especially nutrient-dense kind of animal feed. High-quality fiber with characteristics like low density, non-elasticity, high strength and repeatability is produced from the flax stem. Because of these characteristics, the fiber is very sought-after and ideal for use as thread and rope, which can be mixed with jute, cotton and hemp to enhance the quality of textiles. In addition to oil and fiber, lignin is another important substance derived from linseed. Because of its high linolenic acid content, linseed oil has better-drying properties and is therefore, an essential ingredient in paints, varnishes, oil cloth, and printer ink. Despite the huge benefits of linseed, it is grown in the world with annual production and productivity of 2.52 million tonnes and 923 kg per ha, while national production is 0.15 million tonnes from 0.32 million ha area with productivity of 473 kg per ha (Anonymous 2023) [1]. The main factors that cause the low yield of linseed are cultivation on marginal lands, biotic and abiotic stresses, inadequate crop management, and a lack of suitable hybrids.

(Nirala *et al*. 2018) [6].

The success of any hybrid breeding programme depends upon the choice of parents and clear knowledge of gene action for specific characters. Combining ability is a powerful tool to select good combiners and thus select the appropriate parental lines for the hybridization programme. In addition, the nature of gene action will help to develop an efficient crop improvement programme. (Venkatesh *et al.* 2001) [15].

Materials and Methods

The present investigation was carried out at Experimental Farm, Department of Genetics and Plant Breeding, College of Agriculture, Latur, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani. The objectives of the present investigation were to estimate the general and specific combining ability effect and to study the nature of gene action for seed yield and yield contributing traits using ten parents and cross combinations in Line x Tester (6 x 4) mating design. The resulting 24 F_1s were evaluated along with their parents *i.e.* six diverse lines *viz*., FR-111, GS-105, JLS-395, ES-1445, EC-41741 and Mutant-02, four testers with broad genetic base and wider adaptability *viz*., GS-09, LSL-93, RLC-04 and EI-5511 along with two checks TL-99 and LSL-93 in randomized block design (RBD) with two replications during *Rabi*-2024. The hybrids and plants were sown in single rows of 2-meter length with inter and intra-row spacing of 30 cm and 5 cm, respectively. All the recommended agronomic package of practices and plant protection measures were followed timely to raise good crop. Five plants were selected randomly in each replication from each parent and hybrid and observations were recorded for ten traits *viz.*, days to 50 percent flowering, days to maturity, plant height (cm), number of branches per plant, number of capsules per plant, number of seeds per capsule, 1000 seed weight (g), seed yield per plant (g), harvest index (%) and oil content (%). The mean values were calculated and used for statistical analysis. The data recorded were analyzed as per the method suggested by Spraug and Tautum (1942).

Results and Discussion

The analysis of variance for combining ability is given in Table No. 1 revealed that there is significant variation present among treatments, parents, lines, testers and crosses for all the characters under study. For lines *v/s* testers there is significant variation present for all the characters except for a number of seeds per capsule, seed yield per plant and harvest index (%) this showed that there is sufficient amount of variation present in experimental material. Similar results were also reported by Dakhore *et al*. (1987) [2], Thakur *et al*. (1987) [14] and Singh *et al*. (2006) [11].

Table No. 2 displays the estimations of the GCA effects of the ten parents (six lines and four testers) for each of the ten characters. The parent's value was divided into three categories: good, average and poor general combiners based on the combining ability effects. Parents with positive but non-significant GCA effects were regarded to be average general combiners, parents with negative GCA effects were regarded as poor general combiners and parents with significant GCA effects in the desired direction were regarded as good general combiners. An overall appraisal of GCA effects indicated that none of the parents was good general combiner simultaneously for all the characters studied. However, among the lines, ES-1445 (0.428) reported highest significant GCA effect for seed yield per plant. It also showed significant effect in desirable direction for the characters *viz*., plant height (-1.452), number of branches per plant (0.229), number of seeds per capsule (0.381), 1000 seeds weight (0.633) and oil content (0.320). Another line, EC-41741showed a significant GCA effect in the desired direction for traits such as plant height (-1.759), number of branches per plant (0.229), number of capsules per plant (10.45), number of seeds per capsule (0.403) and seed yield per plant (0.293). Among the testers, EI-5511 showed the highest significant SCA effect for seed yield per plant (0.338). It has also reported significant GCA effect in desirable direction for the traits *viz*., number of branches per plant (0.267), number of capsules per plant (7.231) and 1000 seeds weight (0.005). Hence, the parent's *viz*., ES-1445, EC-41741 and EI-5511 which are good general combiners for most of the characters are considered as potential parents and could be utilized in the further breeding programme to exploit maximum genetic variability and combine more characters by involving fewer numbers of parents in crossing programme.

SCA of a cross is the estimation and understanding of the effect of non-additive gene action for a character. The non-additive gene action of a character is an indicator for the selection of a hybrid combination. Therefore, a highly significant SCA effect is desirable for a successful hybrid breeding programme. The estimates of effects for 24 hybrids for all ten characters are presented in Table No. 3 Among the crosses, ES-1445 x GS-09 (-2.167), FR-111 x GS-09 (-2.417) and JLS-395 x RLC-04 (-1.50) reported negatively significant SCA effect for the character 50 per cent flowering. Crosses, ES-1445 x EI-5511 (-5.00), FR-111 x GS-09 (-4.833) and GS-105 x RLC-04 (-4.750) manifested negatively significant SCA effect for days to maturity. Similar results were registered by Patil and Chopde (1981) [8], Singh *et al.* (1983) [10], Dakhore *et al.* (1987) [2], Ratnaparkhi *et al*. (2005) [9] and Kumar *et al.* (2013) [4].

In the case of plant height (cm), number of branches per plant, number of capsules per plant, number of seeds per capsule, 1000 seed weight (g), seed yield per plant (g), harvest index (%) and oil content (%) positive SCA was desirable. Out of 24 crosses evaluated, ten crosses exhibited highly significant SCA effect for seed yield per plant. The cross, GS-105 x EI-5511 (1.225) manifested the highest significant SCA effect followed by FR-111 x LSL-93 (0.692), JLS-395 x GS-09 (0.669), JLS-395 x LSL-93 (0.515) and EC-41741 x RLC-04 (0.499) whereas, remaining crosses showed negatively significant or non-significant SCA effect. When SCA is significantly positive for yield and its attributing characters, the use of the heterosis breeding method is desirable. These traits can be improved by biparental mating and reciprocal recurrent selection and exploitation of heterosis in hybrids. Similar results were reported by, Ratnaparkhi *et al.* (2005) [9], Sood *et al.* (2011) [12], Kumar *et al*. (2013) [4] and Kumar *et al.* (2016) [3].

The ratio of additive variance to the dominance variance indicates the type of gene action involved in governing the characters. If the additive variance is greater than the dominance variance indicates the character is governed by additive gene action. If dominance variance is greater than additive variance it indicates that, the character is governed by non-additive gene action. The value of estimation of GCA and SCA variance, their ratios and gene action are presented in Table No.4. Characters like days to 50 per cent flowering (2.30), days to maturity (1.83), plant height (8.75), 1000 seeds weight (1.12) and oil content (3.02) indicated the presence of additive gene action as δ^2GCA: δ^2SCA ratio is more than unity. On the other hand, characters such as number of branches per plant (0.28), number of capsules per plant (0.41), number of seeds per capsule (0.68), seed yield per plant (0.22) and harvest index (0.84) indicated the presence of non-additive gene action as the δ^2GCA: δ^2SCA ratio is less than unity. These results were reported earlier by Yang *et al.* (1988) [16], Sood *et al.* (2011) [12], Mishra *et al.* (2013) [5] and Pali and Mahato (2014) [7].

At last, it can be concluded that, there is close relation between GCA and *per se* performance of the parent for most of the characters under study. The parents, ES-1445, EC-41741, EI-5511 and RLC-04 turned out as good general combiners for seed yield per plant and can be used as parents in the heterosis breeding programme. When the SCA effects of the crosses were compared to their mean performance, it became clear that the ranking based on SCA effects did not always match the ranking based on performance *per se* and crosses with high mean performance did not always have high SCA effects. The *per se* performance of the crosses and their SCA effects did not consistently correlate. It is possible that estimating SCA effects may not always result in the best hybrid combination option. Therefore, it may be more practical and realistic to select the best possible cross combination based on *per se* performance. The characters which are governed by additive gene action are fixable and selection based on these characters is beneficial for the improvement of variety. On the other hand, characters which are governed by non-additive gene action are not fixable and exploitation of heterosis is beneficial for such characters.

Table 1: Analysis of variance for combining ability for different ten characters including parents in Linseed (*Linum usitatissimum* L.)

Source of Variation	D.F.	Days to 50 per cent flowering	Days to maturity	Plant height (cm)	Number of branches per plant	Number of capsules per plant	Number of seeds per capsule	1000 seed weight (g)	Seed yield per plant (g)	Harvest index (%)	Oil content (%)
Replications	1	7.779	0.235	6.578	0.382	5.308	0.372	0.545	0.313	6.715	0.006
Treatments	33	41.872**	125.36**	163.27**	1.049**	546.32**	0.969**	2.19**	0.820**	59.60**	19.78**
Parents	9	69.605**	171.20**	199.15**	0.373*	194.86**	0.538**	2.060**	0.279*	61.30**	19.42**
Lines	5	49.550**	82.200**	28.84**	0.203	219.42**	0.598**	2.019**	0.343*	35.34*	4.23**
Testers	3	97.333**	292.50**	508.52**	0.561*	141.18**	0.608**	0.601*	0.239*	115.89**	41.92**
Lines v/s Testers	1	86.70**	252.30**	122.61**	0.660*	233.16**	0.027	6.645**	0.077	27.32	27.86**
Parents v/s Crosses	1	8.662*	24.474**	281.97**	14.070**	3844.26**	9.0821**	0.094	4.670**	110.39**	16.84**
Crosses	23	32.463**	111.81**	144.07**	0.747**	540.46**	0.753**	2.333**	0.864**	56.72**	20.05**
Error	33	1.779	2.05	1.92	0.128	18.04	0.869	0.19	0.10	9.91	0.55

* and ** indicated significance at 5 and 1 percent level, respectively.

Table 2: Estimates of general combining ability (GCA) of lines and testers for yield and its contributing traits in linseed (*Linum usitatissimum* L.)

Parents	Days to 50 percent flowering	Days to maturity	Plant height (cm)	No. of branches per plant	No. of capsule per plant	No. of seeds per Capsule	1000 Seed Weight (cm)	Seed yield per plant (g)	Harvest index (%)	Oil content %
Line										
FR-111	-2.583**	-3.667**	-0.889**	-0.633**	0.592	-0.130	0.398**	0.068*	-1.573**	-0.906**
GS-105	-2.833**	-4.917**	2.597**	-0.296**	-8.053**	0.460**	-0.569**	-0.473**	1.898	0.794**
JLS-395	1.667*	2.833**	2.183**	0.192**	12.51**	-0.455**	-0.552**	0.090*	-0.831**	1.339**
ES-1445	3.167**	5.333**	-1.452**	0.229**	-0.511	0.381**	0.633**	0.428**	0.042	0.320*
EC-41741	2.417**	3.883**	-1.759**	0.242**	10.45**	0.403**	-0.793**	0.293**	-1.376**	-0.384**
Mutanat-02	-1.833**	-3.167**	-0.680**	0.267**	-15.00**	-0.658**	0.833**	-0.407**	1.840	-1.161**
S.E.(Gi)	0.471	0.506	0.490	0.126	1.502	0.104	0.154	0.113	1.113	0.262
S.E.(Gi-Gj)	0.667	0.716	0.693	0.179	2.124	0.147	0.218	0.160	1.574	0.371
CD @5%	1.37	1.48	1.43	0.37	4.39	0.30	0.452	0.33	3.25	0.76
CD @1%	1.87	2.01	1.94	0.50	5.96	0.41	0.614	0.44	4.41	1.04
Testers										
GS-09	2.667**	4.583**	6.632**	0.033**	5.857**	0.265**	-0.966**	0.033	-3.500**	-3.029**
LSL-93	-2.667**	-5.083**	-7.489**	-0.183**	-8.017**	0.006	0.337**	-0.219*	1.557	2.096**
RLC-04	-2.50**	-5.25**	-8.140**	-0.050**	-5.071**	-0.265**	0.624**	-0.152	5.380**	3.239**
EI-5511	2.50**	5.75**	8.998**	0.267**	7.231**	-0.005	0.005**	0.338**	-3.437**	-2.306**
S.E.(Gi)	0.385	0.413	0.400	0.103	1.226	0.085	0.126	0.092	0.901	0.214
S.E.(Gi-Gj)	0.544	0.585	0.566	0.146	1.734	0.120	0.178	0.130	1.285	0.303
CD @5%	1.12	1.21	1.17	0.30	3.58	0.24	0.36	0.27	2.65	0.62
CD @1%	1.52	1.64	1.58	0.41	4.86	0.33	0.50	0.36	3.60	0.85

* and ** indicated significance at 5 and 1 per cent, respectively.

Table 3: Estimates of specific combining ability (SCA) for ten characters in linseed (*Linum usitatissimum* L.)

Sr. No.	Crosses	Days to 50 percent flowering	Days to maturity	Plant height (cm)	No. of branches per plant	No. of capsules per plant	No. of seed per Capsule	1000 Seed Weight (cm)	Seed yield per plant (g)	Harvest index (%)	Oil content %
1	FR-111 x GS-09	-2.417*	-4.833**	-1.189	-0.367	-10.683**	-0.415	0.718*	-0.305	-2.749	0.947
2	FR-111 x LSL-93	-0.083	-0.833	-2.533*	0.783**	13.386**	-0.500*	0.389	0.692**	3.609	0.023
3	FR-111 x RLC-04	-0.250	0.00	1.108	-0.450	-4.825	0.140	0.077	-0.026	-0.713	-1.175*
4	FR-111 x EI-5511	2.750**	4.00**	2.615*	0.033	2.123	0.775**	-1.184**	-0.361	0.147	0.205
5	GS-105 x GS-09	3.833**	7.417**	1.770	0.198	-9.968**	-0.025	-0.260	-0.519*	-0.820	-1.788**
6	GS-105 x LSL-93	-0.833	-1.917	-2.975**	-1.204**	-19.484**	-0.026	0.417	-0.822**	5.018*	1.223*

7	GS-105 x RLC-04	-1.00	-4.750**	0.031	0.313	6.720*	-0.090	0.094	0.115	-4.425	1.990**
8	GS-105 x EI-5511	-2.00*	-0.750	1.74	0.696*	22.733**	0.140	-0.251	1.225**	0.227	-1.425*
9	JLS-395 x GS-09	-0.667	-1.333	-0.237	0.408	16.650**	0.510*	-0.242	0.669**	6.303**	2.642**
10	JLS-395 x LSL-93	0.667	-0.667	2.119*	0.358	1.275	-0.191	0.399	0.515*	0.967	-0.922
11	JLS-395 x RLC-04	-1.50*	-1.500	-0.680	-0.075	-4.786	0.025	0.077	-0.097	-1.211	-1.635**
12	JLS-395 x EI-5511	1.50	3.500**	-1.203	-0.692*	-13.139**	-0.345	-0.234	-1.087**	-6.059*	-0.085
13	ES-1445 x GS-09	-2.167*	-2.833*	-1.112	-0.029	16.359**	-0.446*	-0.482	0.257	-1.894	-1.179*
14	ES-1445 x LSL-93	1.167	2.833*	0.829	0.171	-3.90	0.538*	0.154	0.137	-6.686**	-0.203
15	ES-1445 x RLC-04	2.00*	5.00**	1.585	-0.013	-13.508**	-0.146	0.782*	-0.536*	2.777	0.414
16	ES-1445 x EI-5511	-1.00	-5.00**	-1.302	-0.129	1.055	0.054	-0.454	0.124	5.803*	0.969
17	EC-41741 x GS-09	-1.417	-3.083**	-0.509	-0.442	-9.646*	0.277	-0.001	-0.135	0.013	0.415
18	EC-41741 x LSL-93	-0.083	-0.417	-2.283*	-0.492	1.238	0.150	-0.324	-0.583*	-1.213	0.501
19	EC-41741 x RLC-04	1.750	2.750*	-0.037	0.475	18.738**	-0.483*	-0.647*	0.499*	-1.031	-1.593**
20	EC-41741 x EI-5511	-0.250	0.750	2.830**	0.458	-10.330**	0.057	0.972**	0.219	2.231	0.677
21	Mutant-02 x GS-09	2.833**	4.667**	1.277	0.233	-2.712	0.98	0.260	0.015	-0.853	-1.038
22	Mutant-02 x LSL-93	-0.833	-0.667	4.843**	0.383	7.492*	0.031	-1.036**	0.062	-1.695	-0.622
23	Mutant-02 x RLC-04	-1.00	-1.500	-2.006	-0.250	-2.339	0.553*	-0.383	0.044	4.603	2.000**
24	Mutant-02 x EI-5511	-1.00	-2.500	-4.114**	-367	-2.441	-0.682**	1.151**	-0.121	-2.055	-0.340
	SE±	0.94	1.01	0.98	0.25	3.00	0.20	0.30	0.22	2.22	0.52

* and ** indicated significance at 5 and 1 per cent, respectively.

Table 4: Nature of gene action

Sr. No.	Character	δ^2 GCA	δ^2SCA	δ^2GCA / δ^2SCA	Gene action
1	Days to 50% flowering	8.10	3.52	2.30	Additive
2	Day to maturity	29.04	15.85	1.83	Additive
3	Plant height (cm)	50.70	5.79	8.75	Additive
4	No. of branches per plant	0.065	0.277	0.28	Non-additive
5	No. of capsules per plant	78.02	186.31	0.41	Non-additive
6	No. of seed per capsule	0.113	0.164	0.68	Non-additive
7	1000 Seed weight (g)	0.476	0.425	1.12	Additive
8	Seed yield per plant (g)	0.08	0.35	0.22	Non-additive
9	Harvest index (%)	11.05	13.15	0.84	Non-additive
10	Oil content (%)	6.20	2.06	3.02	Additive

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