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Diallel Analysis for Estimation of Combining Ability for Seed Yield and It's Component Traits in Linseed (*Linum usitatissimum* L.)

Divya Mahto[1*], Anshuman Vashistha[1], Suparna Sinha[2], P. K. Singh[3] and Shailesh Marker[1]

[1]Department of Genetics and Plant Breeding, Sam Higgionbottom University of Agriculture, Technology and Sciences, Allahabad-211007 (U.P.), India.
[2]Department of Plant and Breeding Genetics, Bihar Agricultural University, Sabour, Bhagalpur (Bihar), India.
[3]Department of Horticulture (F&FT) Genetics, Bihar Agricultural University, Sabour, Bhagalpur (Bihar), India.

Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present investigation consisted of eight parents of linseed which were crossed as per diallel analysis [1] **(Model 1 and Method 2)** in Rabi 2010-11 to generate 28 crosses (excluding reciprocals). These 28 crosses were evaluated along with eight parents and three checks viz: T-397, Neelum and Allahabad Local in RBD having three replications during 2011-12 at the Field Experimentation Centre of Department of Genetics and Plant Breeding, Sam Higginbottom University of Agriculture, Technology and Sciences, Allahabad. The data were recorded on ten characters to study the combining ability. The significant mean sum of squares for all the ten characters indicated the presence of a substantial amount of variability. *Per se* performance for seed yield and its components depicted that cross M-42 (169) × POLF-19 (1765) was found to be

**Corresponding author: E-mail: divya.mahto@gmail.com;*
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best. Analysis of variance for combining ability showed significant differences for all the characters. The parents FRW-6 (973) and POLF-19 (1765) were good general combiner for seedyield and most of the traits. Highest positive SCA effect for seed yield per plant was depicted by the cross PbD2-42 (2789) × GS-129 (1018).

Keywords: Analysis of variance; combining ability; GCA (General combining ability); heterosis; SCA (Specific combining ability).

1. INTRODUCTION

Linseed (*Linum usitatissimum* L.) is the oldest domesticated and economically important industrialnon-edibleoilseed crop which is cultivated for seed and its fibre since centuries [2]. Linseedis used for oil production and also in food industries because of its nutritional merits, essential poly unsaturated fatty acids such as alpha-linolenic acid and rich supply of soluble dietary fiber. Flaxseed oil is used as an industrial drying oil due to its high linolenic acid content [3]; [4]. However, some flax genotypes have been developed which contain very low levels of linolenic acid in their oil, making them suitable for use as edible-oil [3,5]. The area under cultivation is approximately 1.9 million hectares in India. The average seed yield of linseed in India is 403 Kg/ha which is comparably very low in comparison with world average seed yield that is 943 Kg/ha [6,7]. As per **INDIASTAT database (2010),** in India Linseed area, production and productivity are 0.342 million hectares and 0.15 million tons with the productivity 0.49 tone/ha respectively, however, in Utter Pradesh, it is 0.033 million hectare and 0.015 million tons with the productivity 0.441 tones/ha respectively.

The low seed yield is chiefly due to limited resources available to poor farmers along withnonavailability of high-yielding cultivars [8]. So, the development of high-yielding varieties/lines is needed to compete with other linseed growing countries. Such lines/varieties can easily be developed through suitable hybridization and selection programmes to isolate superior segregants [9]. Pal and Sikka [10] reported that heterosis is a quicker, cheaper and an easier method of developing crop varieties. However, the success of any hybridization programme chiefly depends on combining ability of parents used in crossing programme [11]. Combining ability provides an important tool for selection of desirable parents and to get required information regarding the nature of gene action controlling desirable trait [12]. Generally, plant breeders use **Griffing's diallel mating design** to identify desirable parents along with their specific cross-combinations and toget the knowledge of genetic effects, estimates of general combining ability (GCA), specific combining ability.

2. MATERIALS AND METHODS

The experimental materials consisted of 8 parents who were crossed as per diallel analysis [1] **(Model 1 and Method 2)** in *Rabi* 2010-11 to generate 28 crosses (excluding reciprocals).The seeds of 39 entries (8 parents, 28 F_1 hybrids and three checks) were sown in the field using a randomized complete block design with three replications On 26th November 2011. This experiment was carried out at Field Experimentation Centre of the Departmentof Genetics and Plant Breeding, Sam Higginbottom University of Agriculture, Technology and Sciences, Allahabad (U.P.). Each plot consisted of three rows 30 cm apart and 2 m long with the plant to plant distances of 7 cm. The standard agronomic practices for linseed were followed during the growing season. The plots were fertilized with 45 kg of N, 40 kg of P and 10 kg of K per ha before sowing and 20 kg of N per ha was top dressed into two splits (at branching and grain filling stage). Days to flowering and days to maturity were recorded on plot basis, whereas plant height, primary branches per plant, number of capsules per plant, number of seeds per capsule, seed yield per plant (g), 1000-seed weight (g), and harvest index (%) were recorded using five randomly selected plants from each plot. The mean values of different traits were subjected to Analysis of Variance [13], estimation of heterosis (Turner, 1953), heterobeltiosis (Fonesca and Patterson, 1968), economic heterosis and combining ability analysis [1].

3. RESULTS AND DISCUSSION

The Analysis of variance for flowering and maturity showed significant differences among the parents and hybrids for both days to 50% flowering and days to maturity while significant differences among parent *vs* hybrids for days to maturity. Days to 50% flowering among the hybrids varied from 82.00 days (FRW-6 (973) × GS-129 (1018)) to 98.67 days (FRW-6 (973) × POLF17 (1704)), (Table 1) respectively. Significant mean squares of both general and specific combining abilities revealed the importance of both additive and non-additive gene effects for these two traits; however, low GCA/SCA ratios of for days to 50% flowering (0.18) and days to maturity (0.14) (Table 2) indicated the predominance of non additive gene effects in their inheritance. Our findings are in agreement with Singh et al. [14] and Bhateria et al. [15] who reported the predominance of non-additive genetic effects for days to flowering but inconsistent with those of Kurt and Evans [16] who observed a greater variance of GCA than of SCA for both days to flowering and days to maturity. The highest positive GCA effect was observed for days to 50% flowering in FRW-6 (973) parent (3.02 days, respectively) and highest positive GCA effect was observed for days to maturity in M-42(169) parent (2.17 days, respectively) (Table 3). In contrast, the parent GS-129 (1018) possessed the highest GCA effect for early flowering (-2.12 days), and the parent FRW-6 (973) possessed the highest GCA effect for early maturity (-1.70 days); thus, this parent could be used in recombination breeding for developing early maturing cultivars. TheFRW-6 (973) × POLF17 (1704) hybrid had the highest and significantly positive SCA effects for days to flowering while the M-42 (169) × FRW-6 (973) hybrid showed the same SCA effects for days to maturity (Table 4). On the other hand, the highest negative and significant SCA effects of -5.88 were obtained for early flowering in the FRW-6 (973) × GS-129 (1018) cross and -5.17 for early maturity in the M-42(169) × PbD2-42(2789) cross. Early flowering and maturity is one of the main objectives in breeding programs for flax [16] and the present findings suggest the possibility of effective genetic improvement for early flowering and early maturity in these materials.Genotypes including parents and their hybrids varied significantly for plant height (Table 1). Among the hybrids, M-42 (169) × GS-129 (1018) with 81.7 cm and POLF-19 (1765) × POLF-17 (1704) with 58.6cm had the highest and lowest plant heights, respectively. Analysis of variance for combining ability showed that GCA and SCA were significant for this trait (Table 2). However, the magnitude of SCA variance was several times greater than the GCA one as shown by the low ratio (0.19) of GCA/SCA estimate, which in turn indicated that the greatest amount of genetic variation for this trait was mainly due to thenon-additive gene action. These results are in agreement with the findings of Bhateria et al. [15], but inconsistent with those of Sood et al. [17] who demonstrated that the additive effects were more important for the genetic control of plant height in linseed. Estimates for GCA effects showed that the parents POLF-17 (1704) and PbD2-42 (2789) had significant and negative values (-3.03 and -1.32 cm, respectively), whereas M-42 (169) and FRW-6 (973) parents had the higher, positive and significant GCA values of 4.57 and 0.68 cm, respectively (Table 3). Both negative and positive SCA effects were observed among the hybridsfor plant height (Table 4). SCA effects for plant height varied from -10.37 to 10.60 cm, belonging to GS-234 (1703) × GS-129 (1018) andM-42 (169) × POLF-17 (1704) hybrids, respectively (Table 4). Analysis of variance indicated that the entries effect was a significantdifference for primary branches per plant (Table 1). A range of 3.6 to 8.9 branches per plant observed for the hybrids M-42 (169) × GS-234 (1703) and POLF-17 (1704) × GS-234 (1703), respectively, indicated a high variability among the hybrids. Significant mean squares of GCA and SCA (Table 2) revealed the importance of both additive and non-additive gene effects in genetic variation of primary branches per plant; however, the GCA/SCA ratio (0.23) confirmed the preponderance of non-additive genetic effects in its genetic control. These results were in agreement with earlier report Singh et al. [14] but not with those of Patil and Chopde, [18], Sood et al. [17] who reported higher importance of additive gene actions on the genetic control of primary branches per plant. Estimations for combining ability effects showed positive and significant GCA values of 0.87 and 0.36 for the parents C91538 (456) and POLF-17 (1704), respectively (Table 3). The SCA effects ranged from -1.18 to +2.94 branches per plant obtained for the hybrids C91538 (456) × POLF17 (1704) and POLF-17 (1704) × GS-234 (1703), respectively (Table 4). Since the parents C91538 (456), POLF-17 (1704) and POLF-19 (1765) had higher GCA effects for branching and a good performance for seed yield, it seems that using these parents in recombination breeding programs may accumulate the genes responsible for branching in the recombinant inbred lines.Significant variations in seed yield and its components including number of capsules per plant, number of seeds per capsule, 1000- seed weight and seed yield per plant were observed among the parents and their F1 hybrids (Table 1). Analysis of variance for combining ability showed that GCA and SCA affected seed

Table 1. Mean performances of parents and hybrids for different characters in linseed

S. no	Genotype	Days to 50% flowering	Days to maturity	Plant height (cm.)	primary branches per plant	Capsules per plant	Seeds per capsule	Biological yield per plant (gm.)	Economic yield per plant (gm.)	1000 grain weight (gm.)	Harvest index (%)
1.	M-42(169)	89.00	147.00	76.33	5.70	85.33	9.60	15.26	4.25	6.22	27.85
2.	M-42(169)×FRW-6(973)	85.00	151.66	75.36	3.90	145.60	9.16	13.33	5.25	5.95	39.38
3.	M-42(169)×C91538(456)	83.00	145.33	64.80	5.63	145.06	9.30	9.09	3.12	6.36	34.36
4.	M-42(169)×POLF-19(1765)	86.00	141.00	66.80	5.20	61.60	8.80	26.04	7.90	6.56	30.34
5.	M-42(169)×POLF-17(1704)	84.00	147.00	81.20	4.20	97.20	8.80	18.75	3.99	4.96	21.31
6.	M-42(169)×PbD2-42(2789)	85.00	140.66	68.66	4.16	93.80	9.13	9.09	2.95	7.25	32.50
7.	M-42(169)×GS-234(1703)	86.00	144.00	75.96	3.66	56.06	7.80	8.29	3.00	5.75	36.27
8.	M-42(169)×GS-129(1018)	87.00	145.00	81.76	4.66	60.00	8.60	12.53	3.33	6.43	26.56
9.	FRW-6(973)	86.66	134.00	73.63	5.66	153.66	9.10	11.81	3.94	6.23	33.38
10	FRW-6(973)×C91538(456)	94.00	142.00	72.76	5.96	265.70	5.00	29.22	7.86	7.60	26.91
11.	FRW-6(973)×POLF-19(1765)	95.00	141.66	69.06	5.20	172.66	6.06	25.00	7.19	7.46	28.80
12.	FRW-6(973)×POLF-17(1704)	98.66	144.00	61.13	6.30	253.60	6.60	17.63	4.74	8.80	26.87
13.	FRW-6(973)×PbD2-42(2789)	93.00	140.00	67.06	7.16	165.20	6.70	15.71	4.93	7.12	31.39
14.	FRW-6(973)×GS-234(1703)	92.00	142.33	70.00	5.63	156.80	8.30	31.18	6.28	8.0333	20.15
15.	FRW-6(973)×GS-129(1018)	82.00	140.33	65.66	5.33	52.40	9.00	16.66	6.28	6.82	37.68
16.	C91538(456)	87.00	148.00	68.06	6.33	102.66	9.06	14.04	3.23	6.58	23.02
17.	C91538(456)×POLF-19(1765)	85.00	146.33	73.76	9.16	232.06	8.80	16.24	4.13	6.55	25.45
18.	C91538(456)×POLF-17(1704)	87.00	146.00	65.66	5.86	211.33	8.23	13.75	3.26	7.12	23.76
19.	C91538(456)×PbD2-42(2789)	89.00	145.00	62.33	8.16	150.06	9.06	10.00	3.37	6.74	33.93
20.	C91538(456)×GS-234(1703)	88.00	143.66	72.66	7.16	232.06	6.20	25.00	4.28	6.60	17.18
21.	C91538(456)×GS-129(1018)	84.66	144.00	67.66	6.33	100.76	9.20	11.03	3.05	6.35	27.63
22.	POLF-19(1765)	86.00	133.00	69.16	5.20	60.00	8.70	12.01	3.97	6.56	33.04
23.	POLF-19(1765)×POLF-17(1704)	85.33	146.00	58.66	8.16	152.66	8.60	20.00	6.51	7.46	32.62
24.	POLF-19(1765)×PbD2-42(2789)	90.00	148.00	67.06	6.33	156.66	6.06	14.26	3.87	5.78	27.13
25.	POLF-19(1765)×GS-234(1703)	88.00	142.66	67.20	5.60	111.00	9.13	13.62	4.46	7.70	32.76
26.	POLF-19(1765)×GS-129(1018)	86.00	144.00	70.80	5.63	191.66	6.70	17.77	3.99	7.28	22.44
27.	POLF-17(1704)	84.66	134.33	63.96	5.16	97.66	8.76	15.17	3.93	7.18	25.936
28.	POLF-17(1704)×PbD2-42(2789)	86.00	144.00	68.20	6.20	112.56	7.70	16.30	3.90	7.07	23.96
29.	POLF-17(1704)×GS-234(1703)	87.66	148.66	62.33	8.90	184.20	8.76	9.66	4.00	7.46	41.50
30.	POLF-17(1704)×GS-129(1018)	85.33	145.00	66.06	5.96	144.06	8.33	13.00	3.08	7.70	23.86
31.	PbD2-42(2789)	87.00	145.00	66.06	5.63	47.33	9.06	13.04	2.85	6.96	21.89
32.	PbD2-42(2789)×GS-234(1703)	85.00	140.00	74.60	6.16	55.20	9.20	15.68	3.56	7.51	22.71

S. no	Genotype	Days to 50% flowering	Days to maturity	Plant height (cm.)	primary branches per plant	Capsules per plant	Seeds per capsule	Biological yield per plant (gm.)	Economic yield per plant (gm.)	1000 grain weight (gm.)	Harvest index (%)
33.	PbD2-42(2789)×GS-129(1018)	86.00	146.00	68.20	4.63	167.33	7.63	26.11	7.66	7.13	29.33
34.	GS-234(1703)	78.66	135.33	72.33	4.20	53.90	8.23	14.11	2.96	7.47	20.96
35.	GS-234(1703)×GS-129(1018)	86.66	140.00	59.33	4.60	134.06	8.06	18.00	5.00	7.00	27.86
36.	GS-129(1018)	82.00	137.00	71.60	5.33	87.06	9.10	11.66	3.01	6.52	25.79
37.	T-397(c)	85.00	128.33	76.16	12.76	387.33	8.53	27.66	8.36	7.20	30.32
38.	Allahabad local(c)	78.00	131.00	57.30	11.96	344.00	9.10	21.99	7.06	7.70	32.37
39.	Neelum(c)	88.00	135.000	65.86	4.70	110.36	4.53	14.39	3.21	7.57	22.34
	Mean	**86.72**	**142.11**	**68.85**	**6.11**	**143.35**	**8.17**	**16.51**	**4.56**	**6.94**	**28.24**
	C.V.	1.039	0.8702	0.51	5.08	0.30	2.30	2.51	3.13	1.68	4.62
	F ratio	57.908	53.90	778.38	116.71	95254.77	134.10	609.42	392.23	113.07	55.90
	F Prob.	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	S.E.	0.520	0.714	0.20	0.17	0.25	0.10	0.24	0.08	0.06	0.75
	C.D. 5%	1.465	2.011	2.57	2.50	2.71	1.30	2.67	2.23	1.19	2.12
	C.D. 1%	1.944	2.66	2.76	2.67	2.95	1.40	2.89	2.30	1.25	2.81
	Range Lowest	78.00	128.33	57.30	3.66	47.33	4.53	8.29	2.85	4.96	17.18
	Range Highest	98.66	151.66	81.76	12.76	387.33	9.60	31.18	8.36	8.80	41.50

Table 2. Analysis of variance for combining ability for different characters in linseed

S. no	Characters	Mean sum of squares			
		GCA	**SCA**	**Error**	**GCA/SCA**
		[7]	**[28]**	**[70]**	
1	Days to 50% flowering	4.61**	12.17**	0.293	0.18
2	Days to Maturity	4.72**	16.69**	0.55	0.14
3	Plant height	9.675**	24.74**	0.04	0.19
4	Number of Primary branches per plant	0.62**	1.30**	0.03	0.23
5	Number of Capsules per plants	1362.08**	2922.92**	0.05	0.23
6	Number of Seeds per capsule	0.23**	1.34**	0.01	0.085
7	1000 grain weight	0.18**	0.43**	0.01	0.21
8	Biological yield per plant	4.08**	36.65**	0.06	0.06
9	Harvest index	5.45**	33.55**	0.61	0.08
10	Seed yield per plant	0.58**	2.06**	0.01	0.14

***significant at 1% level of significance respectively*

Table 3. General combining ability effects of parents for different characters in linseed

S no.	Genotypes	Days to 50% flowering	Days to maturity	Plant height	Primary branches per plant	Capsules per plant	Seeds per capsule	1000 grain weight	Biological yield per plant	Harvest index	Seed yield per plant
1	**M-42(169)**	-0.88**	2.17**	4.57**	-0.95**	-35.73**	0.66**	-0.64**	-1.74**	2.23**	-0.17**
2	**FRW-6(973)**	3.02**	-1.70**	0.68**	-0.15*	33.20**	-0.51**	0.22**	2.73**	2.38**	1.06**
3	**C91538(456)**	0.18	2.13**	-0.57**	0.87**	35.51**	-0.02	-0.16**	-0.26**	-1.89**	-0.42**
4	**POLF-19(1765)**	0.45**	-1.13**	-0.98**	0.34**	1.11**	-0.26**	-0.02	1.19**	1.15**	0.62**
5	**POLF-17(1704)**	0.05	0.23	-3.03**	0.36**	16.37**	0.04	0.29**	-0.56**	-0.84**	-0.24**
6	**PbD2-42(2789)**	0.52**	0.67**	-1.32**	0.18*	-19.18**	-0.05	0.05*	-1.18**	-0.94**	-0.38**
7	**GS-234(1703)**	-1.22**	-1.50**	0.53**	-0.22**	-15.01**	-0.02	0.29**	0.47**	-1.38**	-0.33**
8	**GS-129(1018)**	-2.12**	-0.87**	0.12	-0.45**	-16.28**	0.16**	-0.03	-0.66**	-0.72*	-0.14**

*** and *significant at 1% and 5% level of significance respectively*

Table 4. Specific combining ability effects for different characters in linseed

S. no.	Genotypes	Days to 50% flowering	Days to maturity	Plant height	Primary branches per plant	Capsules per plant	Seeds per Capsule	1000 grain weight	Biological yield per plant	Harvest index	Seed yield per plant
1	M-42(169) × FRW-6(973)	-4.11**	8.20**	1.05**	-0.82**	16.20**	0.77**	-0.53**	-3.78**	6.53**	-0.06
2	M-42(169) × C91538(456)	-3.28**	-1.97*	-8.26**	-0.10	13.36**	0.42**	0.26**	-5.02**	5.78**	-0.70**
3	M-42(169) × POLF-19(1765)	-0.55	-3.03**	-5.85**	-0.01	-35.70**	0.15	0.31**	10.47**	-1.27	3.03**
4	M-42(169) × POLF-17(1704)	-2.15**	1.60	10.60**	-1.03**	-15.36**	-0.15	-1.58**	4.93**	-8.32**	-0.01
5	M-42(169) × PbD2-42(2789)	-1.61*	-5.17**	-3.64**	-0.88**	16.78**	0.28*	0.95**	-4.10**	2.97**	-0.91**
6	M-42(169) × GS-234(1703)	1.12	0.33	1.81**	-0.98**	-25.12**	-1.08**	-0.80**	-6.55**	7.18**	-0.92**
7	M-42(169) × GS-129(1018)	3.02**	0.70	8.02**	0.25	-19.91**	-0.46**	0.20**	-1.19**	-3.19**	-0.78**
8	FRW-6(973) × C91538(456)	3.82**	-1.43	3.60**	-0.57*	65.06**	-2.71**	0.64**	10.64**	-1.82	2.80**
9	FRW-6(973) × POLF19(1765)	4.55**	1.50	0.31	-0.81**	6.44**	-1.40**	0.37**	4.96**	-2.96**	1.08**
10	FRW-6(973) × POLF17(1704)	8.62**	2.47*	-5.58**	0.27	72.11**	-1.17**	1.40**	-0.66*	-2.91**	-0.50**
11	FRW-6(973) × PbD2-42(2789)	2.49**	-1.97*	-1.35**	1.32**	19.25**	-0.98**	-0.04	-1.96**	1.71	-0.17
12	FRW-6(973) × GS-234(1703)	3.22**	2.53**	-0.27	0.18	6.68**	0.59**	0.63**	11.87**	-9.09**	1.13**
13	FRW-6(973) × GS-129(1018)	-5.88**	-0.10	-4.19**	0.11	-96.44**	1.11**	-0.26**	-1.53**	7.79**	0.93**
14	C91538(456)× POLF19(1765)	-2.61**	2.33*	6.26**	2.15**	63.53**	0.84**	-0.17**	-0.81*	-2.05*	-0.49**

S. no.	Genotypes	Days to 50% flowering	Days to Maturity	Plant height	Primary branches per plant	Capsule per plant	Seeds per capsule	1000 grain weight	Biological yield per plant	Harvest index	Seed yield per plant
15	C91538(456)× POLF17(1704)	-0.21	0.63	0.21	-1.18**	27.53**	-0.03	0.09	-1.55**	-1.75	-0.49*
16	C91538(456)× × PbD2-42(2789)	1.32	-0.80	-4.83**	1.31**	1.81**	0.90**	-0.04	-4.68**	8.52**	-0.24*
17	C91538(456) × GS-234(1703)	2.05**	0.03	3.65**	0.70**	79.64**	-2.00**	-0.43**	8.68**	-7.79**	0.61**
18	C91538(456) × GS-129(1018)	-0.38	-0.27	-0.94**	0.10	-50.38**	0.82**	-0.36**	-4.16**	2.00*	-0.81**
19	POLF-19(1765)× POLF-17(1704)	-2.15**	3.90**	-6.38**	1.65**	3.27**	0.58**	0.29**	3.25**	4.07**	1.71**
20	POLF-19(1765)× PbD2-42(2789)	2.05**	5.47**	0.31	0.00	42.82**	-1.86**	-1.15**	-1.87**	-1.32	-0.79**
21	POLF-19(1765) × GS-234(1703)	1.79*	2.30*	-1.40**	-0.34	-7.02**	1.17**	0.53**	-4.15**	4.75**	-0.25*
22	POLF-19(1765) × GS-129(1018)	0.69	3.00**	2.60**	-0.07	74.92**	-1.44**	0.43**	1.12**	-6.23**	-0.92**
23	POLF-17(1704)× PbD2-42(2789)	-1.55*	0.10	3.50**	-0.16	-16.55**	-0.53**	-0.16*	1.92**	-2.50*	0.11
24	POLF-17(1704) × GS-234(1703)	1.85**	6.93**	-4.22**	2.94**	50.92**	0.51**	-0.01	-6.36**	15.48**	0.15
25	POLF-17(1704) × GS-129(1018)	0.42	2.63**	-0.08	0.24	12.06**	-0.11	0.55**	-1.90**	-2.82**	-0.96**
26	PbD2-42(2789) × GS-234(1703)	-1.28	-2.17*	6.34**	0.39	-42.54**	1.03**	0.28**	0.28	-3.21**	-0.15
27	PbD2-42(2789) × GS-129(1018)	0.62	3.20**	0.35	-0.91**	70.87**	-0.71**	0.22**	11.84**	2.75**	3.76**
28	GS-234(1703) × GS-129(1018)	3.02**	-0.63	-10.37**	-0.55*	33.44**	-0.31*	-0.15	2.08**	1.72*	1.04**

***,*significant at 1% and 5% level of significance respectively* yield and its components (Table 2), implying that additive and non-additive influenced the inheritance of these traits. The low ratio of GCA/SCA for these traits indicated that the role of non-additive gene effects was more important than the additive ones on the variations in these traits, a finding which agrees well with the results reported elsewhere [15,16,14]. In previous studies,the significant influence of both additive and non-additive genetic effects on the inheritance of seed weight and seed yield per plant was reported [17] and the reported GCA variance was greater than the SCA for seed weight and seed yield per plant [18]. Regarding a number of capsules per plant, significant differences were observed among thehybrids for this trait ranging from 265.7 to 52.4 capsules observed for FRW-6 (973) × C91538 (456) and FRW-6 (973) × GS-129 (1018), (Table 1) respectively. Estimates of combining ability for a number of capsules per plant showed positive and significant GCA effects for C91538 (456) and FRW-6 (973), with the highest value of 35.51 for C91538 (456) (Table 3). The SCA effects for a number of capsules per plant ranging from -96.44 to 79.64 were high and significant in the hybrids FRW-6 (973) × GS-129 (1018) and C91538 (456) × GS-234 (1703) (Table 4). The estimates of combining ability showed that the GCA values for some seeds per capsule was significant and positive for the parents M-42 (169), GS-129 (1018) and POLF-17 (1704) but negative for the parents FRW-6 (973) (Table 3). The highest SCA effect of 1.17 seeds per capsule was obtained for the hybrid POLF-19 (1765) × GS-234 (1703); however, the lowest (-2.71 seeds per capsule) was observed in the hybrid FRW-6 (973) × C91538 (456) (Table 4) A considerable variation was observed for 1000-seed weight among the hybrids and the highest (8.8 g) and the lowest (4.9 g) mean for this trait belonged to FRW-6 (973) × POLF17 (1704) and, M-42 (169) × POLF-17 (1704) respectively. The parents POLF-17 (1704), FRW-6 (973) andGS-234 (1703) had positive and significant GCA values for 1000-seed weight (Table 3). Positive and significant SCA effects were observed in some cross combinations (Table 4). The highest positive value of SCA was 1.40 g observed in cross FRW-6 (973) × POLF17 (1704) and the lowest value of -1.58g belonged to the hybrid M-42 (169) × POLF-17 (1704) (Table 4). Highly significant differences were observed among the F1 hybrids and the highest seed yield per plant and were ranged from 2.95 to 7.90 for the hybrids M-42 (169) × POLF-19(1765) and M-42 (169) × PbD2-42 (2789). Based on the estimates of GCA effects, the parental genotypes FRW-6 (973) and POLF-19 (1765) combining ability (Table 3), indicating that they could be used as good combiners for recombinant breeding programmes. The SCA effects of the hybrids for seed yield per plant were significantly different, and high SCA values of 3.76 g and 3.03 g were obtained for PbD2-42 (2789) × GS-129 (1018) and M-42 (169) × POLF-19 (1765), respectively (Table 4). For seed yield which is the most important economic trait, there was a high variation among both the parents and their F1 hybrids. The estimate of GCA/SCA ratio for seed yield (0.14) (Table 2) confirmed the importance of non-additive gene actions in governing this trait. The analysis of variance for combining ability of harvest index showed that both GCA and SCA effects were significant for this trait (Table 2). The GCA/SCA ratio for this character was 0.08, showing the importance of non-additive gene actions in the genetic control of harvest index. The higher value of GCA effect of 2.38 and 2.23 for harvest index was obtained in parents FRW-6 (973) and M-42 (169) respectively (Table 3). Development of linseed cultivars with a high harvest index is the breeder's major purpose [16] and the high genetic variation for this trait in this study indicates the possibility for its improvement in flax breeding.

4. CONCLUSION

The GCA effect for seed yield per plant of the parents of the hybrids are M-42 (169) (-0.17**), and POLF-19 (1765) (0.62**) and SCA effect for seed yield per plant of the hybrids is M-42 (169) x POLF-19 (1765) (3.03**). The parents FRW-6 (973) and POLF-19 (1765) were good general combiners for seed yield and most of the traits. Therefore, these parents can be used for the development of superior transgressive hybrids.

Since these data are based on one location testing, it required further testing to confirm the consistency in the performance of hybrids over the location and years to substantiate the results.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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