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Assessment of combining ability and heterosis for seed yield and related traits in linseed (*Linum usitatissimum* L.) through diallel analysis

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Abstract
The study involved eight linseed (*Linum usitatissimum* L.) genotypes, which were crossed following a diallel cross design (Griffing 1956 Model 1, Method 2) during the Rabi season of 2010-11, resulting in 28 distinct hybrid combinations (excluding reciprocal crosses). These 28 F1 hybrids, together with the eight parental lines and three check varieties (T-397, Neelum, and Allahabad Local), were evaluated using a Randomized Block Design (RBD) with three replications during the 2011-12 cropping season at the Field Experimentation Centre, Department of Genetics and Plant Breeding, SHIATS, Allahabad. A total of ten agronomic traits were recorded to assess both heterosis and combining ability. The analysis of variance (ANOVA) showed significant variation across all traits, indicating considerable genetic diversity within the study population. The cross M-42(169) × POLF-19(1765) showed the best performance in terms of seed yield and its components. Heterosis analysis revealed that the cross PbD2-42(2789) × GS-129(1018) exhibited the highest heterosis, heterobeltiosis, and economic heterosis for seed yield per plant. Combining ability analysis indicated significant differences for all traits, with FRW-6(973) and POLF-19(1765) identified as the best general combiners for seed yield and other important traits. The cross PbD2-42(2789) × GS-129(1018) demonstrated the highest positive specific combining ability (SCA) effect for seed yield per plant.

Keywords: Heterosis, combining ability, seed yield, linseed (*Linum usitatissimum* L.)

Introduction

Linseed (*Linum usitatissimum* L.) is one of the earliest domesticated crops and holds significant economic value as an industrial non-edible oilseed. It has been cultivated for centuries for both its seeds and fiber [1]. While linseed is primarily grown for its oil, it also plays an important role in the food industry due to its nutritional properties. The seeds are rich in essential polyunsaturated fatty acids, such as alpha-linolenic acid, and contain high levels of soluble dietary fiber. Linseed oil, known for its abundant linolenic acid, is widely used as an industrial drying oil [2]. In our country, linseed occupies 3.84 lakh ha area with a production of 1.54 lakh tonne and contributes about 10.81% and 5.31%, respectively to the global area. The low yield can be attributed to the limited resources available to smallholder farmers and the absence of high-yielding varieties [4]. To improve competitiveness with other linseed-producing countries, the development of high-yielding varieties is crucial. Such varieties can be achieved through well-planned hybridization and selection programs aimed at identifying superior segregants [5]. Combining ability analysis is an effective tool for selecting ideal parent lines and understanding the genetic control of important traits [6].

Materials and Methods

The experimental materials for this study included eight parental lines, which were crossed following a diallel cross design [7] during the Rabi season of 2010-11, resulting in 28 hybrid combinations (excluding reciprocal crosses). A total of 39 entries, consisting of the 8 parental lines, 28 F1 hybrids, and 3 check varieties, were sown on November 26, 2011, at the Field Experimentation Centre, Department of Genetics and Plant Breeding, SHIATS, Allahabad (U.P.).

The experimental layout followed a Randomized Block Design (RBD) with three replications. Data for days to flowering and days to maturity were recorded at the plot level. For other traits, such as plant height, number of primary branches per plant, number of capsules per plant, number of seeds per capsule, seed yield per plant (in grams), 1000-seed weight (in grams), and harvest index (%), measurements were taken from five randomly selected plants in each plot. The mean values for these traits were analyzed using analysis of variance (ANOVA) [9]. Further statistical analyses were carried out to estimate heterosis, heterobeltiosis, economic heterosis, and combining ability.

Results and Discussion

Flowering and Maturity: The analysis of variance (ANOVA) showed significant differences between both the parental lines and hybrids for days to 50% flowering and days to maturity, with notable variations observed between parents and hybrids for days to maturity (Table 1). The days to 50% flowering in the hybrids ranged from 82.05 days in the cross FRW-6(973) × GS-129(1018) to 98.71 days in the cross FRW-6(973) × POLF17 (1704) (Table 2). Significant mean squares for both general combining ability (GCA) and specific combining ability (SCA) underscored the involvement of both additive and non-additive genetic factors in the inheritance of these traits. However, the relatively low GCA/SCA ratios for days to 50% flowering (0.18) and days to maturity (0.14) (Table 3) suggested that non-additive genetic effects played a dominant role in controlling these traits.

Our findings are consistent with the observations of [8] and [9], who also reported the dominance of non-additive genetic effects for days to flowering. However, our results differ from those of [10], who found a higher variance in general combining ability (GCA) compared to specific combining ability (SCA) for both days to flowering and maturity. Specifically, the parent GS-129(1018) exhibited the highest GCA effect for early flowering, with a reduction of -2.12 days, while FRW-6(973) showed the highest GCA effect for early maturity, with a decrease of -1.70 days (Table 4.1). These parents, therefore, hold potential for use in recombination breeding programs aimed at developing early-maturing linseed varieties.

The cross FRW-6(973) × POLF17(1704) exhibited the highest and significantly positive specific combining ability (SCA) effects for days to flowering, while the hybrid M-42(169) × FRW-6(973) showed the most significant positive SCA effects for days to maturity (Table 4.2). In contrast, the cross FRW-6(973) × GS-129(1018) demonstrated the highest negative and significant SCA effect for early flowering (-5.88 days), and M-42(169) × PbD2-42(2789) displayed the highest negative SCA effect for early maturity (-5.17 days) (Table 4.2).

For early maturity, the hybrids M-42(169) × PbD2-42(2789), M-42(169) × POLF-19(1765), and FRW-6(973) × C91538 (456) showed significant heterobeltiosis, (Table 5), indicating superior performance compared to the best parent for this trait. Early flowering and maturity are important goals in flax breeding [10], and our results suggest that genetic improvement for these traits can be effectively achieved using the genotypes involved in this study.

Plant Height

The genotypes, including both the parents and their hybrids, showed significant variation for plant height (Table 1). Among the hybrids, the cross M-42(169) × GS-129(1018) produced the tallest plants, measuring 81.81 cm, while POLF-19(1765) × POLF-17(1704) had the shortest plants, at 58.70 cm. The analysis of variance (ANOVA) for combining ability revealed significant effects for both general combining ability (GCA) and specific combining ability (SCA) for plant height. However, the GCA/SCA ratio of 0.19 (Table 3) indicated that non-additive genetic effects played a more dominant role in the genetic variation observed for this trait. These results are in agreement with the findings of [8], but contrast with those of [11], who reported a greater influence of additive genetic effects.

Both positive and negative specific combining ability (SCA) effects for plant height were observed in the hybrids (Table 4.2). The SCA effects varied from -10.37 cm for the cross GS-234(1703) × GS-129(1018) to +10.60 cm for the hybrid M-42(169) × POLF-17(1704) (Table 4.2).

Primary Branches per Plant

The analysis of variance (ANOVA) showed significant differences among the entries for the number of primary branches per plant (Table 1). The hybrid crosses displayed considerable variation in branch number, with M-42(169) × GS-234(1703) having 3.71 branches per plant, and POLF-17(1704) × GS-234(1703) producing 8.93 branches per plant, indicating substantial diversity among the hybrids. The significant mean squares for both general combining ability (GCA) and specific combining ability (SCA) highlighted the influence of both additive and non-additive genetic effects on this trait. However, the GCA/SCA ratio of 0.23(Table 3) further indicated that non-additive genetic effects played a dominant role in the inheritance of primary branches per plant. These results align with the findings of [8], but differ from those reported by [12].

Estimates of combining ability revealed positive and significant general combining ability (GCA) effects of 0.87 for the parent C91538(456) and 0.36 for POLF-17(1704) (Table 4.1). The specific combining ability (SCA) effects for primary branches per plant ranged from -1.18 to +2.94, observed in the hybrids C91538(456) × POLF-17(1704) and POLF-17(1704) × GS-234(1703), respectively (Table 4.2). Additionally, notable and significant heterosis over the midparent was recorded, with values varying from -35.67% to +72.26% across the different crosses.

The parents C91538(456), POLF-17(1704), and POLF-19(1765) (Table 4.1) exhibited higher general combining ability (GCA) effects for branching and also performed well in terms of seed yield. These parents could therefore be beneficial in recombination breeding programs. Incorporating these parents into breeding programs could help gather genes linked to better branching, which may improve the performance of future generations of recombinant inbred lines.

Seed Yield and Its Components

There was significant variation in seed yield and its component traits, such as the number of capsules per plant, number of seeds per capsule, 1000-seed weight, and seed yield per plant, among the parental lines and their F1 hybrids (Table 1). The analysis of variance (ANOVA) for combining ability showed that both general combining ability (GCA) and specific combining ability (SCA) had a significant impact on these traits (Table 3). This indicates that both additive and non-additive genetic effects contribute to the observed variation, with non-additive effects having a more dominant influence, which aligns with the results of [8].

Significant differences were observed among the hybrids for the number of capsules per plant, with counts ranging from 265.80 in the cross FRW-6 (973) × C91538 (456) to 52.50 in FRW-6(973) × GS-129(1018) (Table 2). The specific combining ability (SCA) effects for this trait showed a wide range, from -96.44 to +79.64, with highly significant effects noted in the hybrids FRW-6(973) × GS-129(1018) and C91538(456) × GS-234(1703) (Table 4.2). In several crosses, significant heterosis was observed over both the mid-parent and better-parent, with the highest heterobeltiosis of 161.11% recorded in the hybrid POLF-19(1765) × PbD2-42(2789) (Table 5).

For the number of seeds per capsule, the general combining ability (GCA) effects were positive and significant for the parents M-42(169), GS-129(1018), and POLF-17(1704), while negative GCA effects were recorded for FRW-6(973) (Table 4.1). The highest specific combining ability (SCA) effect of 1.17 seeds per capsule (Table 4.2)was found in the hybrid POLF-19(1765) × GS-234(1703), whereas the lowest SCA effect of -2.71 seeds per capsule was observed in the cross FRW-6(973) × C91538(456). Several hybrid combinations showed significant and positive heterosis over both the mid-parent and better-parent, with the highest heterobeltiosis of 4.98% seen in POLF-19(1765) × GS-234(1703) (Table 5).

There was substantial variation in 1000-seed weight among the hybrids, with the highest average of 8.85 g recorded in the cross FRW-6(973) × POLF17 (1704), and the lowest of 5.01 g in M-42(169) × POLF-17(1704). The parents POLF-17(1704), FRW-6(973), and GS-234(1703) showed positive and significant general combining ability (GCA) effects for 1000-seed weight (Table 4.1). Several hybrids also exhibited significant positive specific combining ability (SCA) effects, with the highest SCA value of 1.40 g in FRW-6(973) × POLF17(1704) and the lowest SCA value of -1.58 g in M-42(169) × POLF-17(1704) (Table 4.2). Some hybrids demonstrated significant heterosis over both mid-parent and better-parent, with the highest heterobeltiosis of 22.45% observed in FRW-6(973) × POLF17 (1704) (Table 5).

Seed yield per plant, an important economic trait, showed highly significant variation among the F1 hybrids, with yields ranging from 2.95 g in M-42(169) × PbD2-42(2789) to 7.95 g in M-42(169) × POLF-19(1765) (Table 2). According to the general combining ability (GCA) estimates, FRW-6(973) and POLF-19(1765) were identified as strong combiners for seed yield, suggesting their potential for use in breeding programs. The specific combining ability (SCA) effects for seed yield per plant varied considerably among the hybrids, with the highest SCA values of 3.76 g and 3.03 g seen in PbD2-42(2789) × GS-129(1018) and M-42(169) × POLF-19(1765), respectively (Table 4.2). Significant and favorable heterosis was observed in most of the crosses, consistent with the findings of [13]. The highest heterobeltiosis of 154.03% was recorded in the cross PbD2-42(2789) × GS-129(1018) (Table 5).

Seed yield, a key economic trait, exhibited substantial variation among the parental lines and their F1 hybrids. The GCA/SCA ratio for seed yield (0.14) (Table 3).Further supported the dominance of non-additive genetic effects in controlling this trait's inheritance.

Table-1: Analysis of variance for ten yield attributing traits in Linseed

S. No.	Characters	Mean Sum of Squares						
		Replications	**Treatments**	**Parents**	**Hybrids**	**P v_s Hy**	**Error**	**Total**
		2	35	7	27	1	70	107
1	Days to 50% flowering	1.23	43.94**	32.95**	44.48**	106.35**	0.88	14.97
2	Days to Maturity	0.19	55.89**	120.38**	24.81**	443.63**	1.65	19.36
3	Plant height	0.13	88.53**	50.34**	100.36**	36.66**	0.13	29.04
4	Number of Primary branches per plant	0.19	5.10**	1.13**	6.13**	5.09**	0.10	1.74
5	Number of Capsules per plants	0.35	11101.44**	3512.47**	11065.58**	65192.55**	0.18	3631.13
6	Number of Seeds per capsule	0.08	3.92**	0.47**	4.38**	15.79**	0.03	1.31
7	1000 grain weight	0.02	1.59**	0.60**	1.86**	1.02**	0.01	0.53

**significant at 1% level of significance respectively

Table 2: 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	76.3333	5.7000	85.3333	9.6000	15.2667	4.2533	6.2233	27.8560
2.	M-42(169)×FRW-6(973)	85.00	151.66	75.3667	3.9000	145.6000	9.1667	13.3300	5.2500	5.9500	39.3800
3.	M-42(169)×C91538(456)	83.00	145.33	64.8000	5.6333	145.0667	9.3000	9.0967	3.1267	6.3600	34.3667
4.	M-42(169)×POLF-19(1765)	86.00	141.00	66.8000	5.2000	61.6000	8.8000	26.0400	7.9533	6.5600	30.3467
5.	M-42(169)×POLF-17(1704)	84.00	147.00	81.2000	4.2000	97.2000	8.8000	18.7500	3.9967	5.01	21.3133
6.	M-42(169)×PbD2-42(2789)	85.00	140.66	68.6667	4.1667	93.8000	9.1333	9.0967	2.9567	7.2567	32.5033
7.	M-42(169)×GS-234(1703)	86.00	144.00	75.9667	3.7167	56.0667	7.8000	8.2933	3.0067	5.7500	36.2700
8.	M-42(169)×GS-129(1018)	87.00	145.00	81.8167	4.6667	60.0000	8.6000	12.5333	3.3300	6.4333	26.5667
9.	FRW-6(973)	86.66	134.00	73.6333	5.6667	153.6667	9.1000	11.8133	3.9433	6.2300	33.3800
10.	FRW-6(973)×C91538(456)	94.00	142.00	72.7667	5.9667	265.7500	5.0000	29.2233	7.8667	7.6000	26.9133
11.	FRW-6(973)×POLF-19(1765)	95.00	141.66	69.0667	5.2000	172.6667	6.0667	25.0000	7.1900	7.4667	28.8067
12.	FRW-6(973)×POLF-17(1704)	98.71	144.00	61.1333	6.3000	253.6000	6.6000	17.6333	4.7400	8.8500	26.8767
13.	FRW-6(973)×PbD2-42(2789)	93.00	140.00	67.0667	7.1667	165.2000	6.7000	15.7133	4.9333	7.1233	31.3933
14.	FRW-6(973)×GS-234(1703)	92.00	142.33	70.0000	5.6333	156.8000	8.3000	31.1867	6.2867	8.0333	20.1533
15.	FRW-6(973)×GS-129(1018)	82.05	140.33	65.6667	5.3333	52.4500	9.0000	16.6600	6.2800	6.8200	37.6897
16.	C91538(456)	87.00	148.00	68.0667	6.3333	102.6667	9.0667	14.0400	3.2333	6.5800	23.0233
17.	C91538(456)×POLF-19(1765)	85.00	146.33	73.7667	9.1667	232.0667	8.8000	16.2400	4.1333	6.5567	25.4533
18.	C91538(456)×POLF-17(1704)	87.00	146.00	65.6667	5.8667	211.3333	8.2333	13.7500	3.2667	7.1200	23.7600
19.	C91538(456)×PbD2-42(2789)	89.00	145.00	62.3333	8.1667	150.0667	9.0667	10.0000	3.3733	6.7467	33.9300

20.	C91538(456)×GS-234(1703)	88.00	143.66	72.6667	7.1667	232.0667	6.2000	25.0000	4.2867	6.6000	17.1867
21.	C91538(456)×GS-129(1018)	84.66	144.00	67.6667	6.3333	100.7667	9.2000	11.0367	3.0500	6.3500	27.6313
22.	POLF-19(1765)	86.00	133.00	69.1667	5.2000	60.0000	8.7000	12.0133	3.9700	6.5600	33.0400
23.	POLF-19(1765)×POLF-17(1704)	85.33	146.00	58.7067	8.1667	152.6667	8.6000	20.0000	6.5133	7.4600	32.6200
24.	POLF-19(1765)×PbD2-42(2789)	90.00	148.00	67.0667	6.3333	156.6667	6.0667	14.2633	3.8700	5.7800	27.1300
25.	POLF-19(1765)×GS-234(1703)	88.00	142.66	67.2000	5.6000	111.0000	9.1333	13.6200	4.4633	7.7000	32.7667
26.	POLF-19(1765)×GS-129(1018)	86.00	144.00	70.8000	5.6333	191.6667	6.7000	17.7700	3.9900	7.2833	22.4467
27.	POLF-17(1704)	84.66	134.33	63.9667	5.1667	97.6667	8.7667	15.1767	3.9333	7.1867	25.9367
28.	POLF-17(1704)×PbD2-42(2789)	86.00	144.00	68.2000	6.2000	112.5667	7.7000	16.3000	3.9067	7.0700	23.9600
29.	POLF-17(1704)×GS-234(1703)	87.66	148.66	62.3333	8.9500	184.2000	8.7667	9.6667	4.0033	7.4633	41.5067
30.	POLF-17(1704)×GS-129(1018)	85.33	145.00	66.0667	5.9667	144.0667	8.3333	13.0000	3.0867	7.7033	23.8600
31.	PbD2-42(2789)	87.00	145.00	66.0667	5.6333	47.3333	9.0667	13.0433	2.8567	6.9600	21.8967
32.	PbD2-42(2789)×GS-234(1703)	85.00	140.00	74.6000	6.1667	55.2000	9.2000	15.6833	3.5667	7.5133	22.7167
33.	PbD2-42(2789)×GS-129(1018)	86.00	146.00	68.2000	4.6333	167.3333	7.6333	26.1167	7.6633	7.1333	29.3367
34.	GS-234(1703)	78.66	135.33	72.3333	4.2000	53.9000	8.2333	14.1167	2.9600	7.4700	20.9667
35.	GS-234(1703)×GS-129(1018)	86.66	140.00	59.3333	4.6000	134.0667	8.0667	18.0000	5.0033	7.0067	27.8633
36.	GS-129(1018)	82.00	137.00	71.6000	5.3333	87.0667	9.1000	11.6600	3.0167	6.5200	25.7967
37.	T-397(c)	85.00	128.33	76.1667	12.7667	387.3333	8.5333	27.6667	8.3600	7.2000	30.3200
38.	Allahabad local(c)	78.00	131.00	57.3000	11.9667	344.0000	9.1000	21.9967	7.0667	7.7000	32.3767
39.	Neelum(c)	88.00	135.000	65.8667	4.7000	110.3667	4.5333	14.3933	3.2167	7.5767	22.3433
	Mean	86.72	142.11	68.8547	6.1179	143.3530	8.1735	16.5177	4.5603	6.9439	28.2483
	C.V.	1.039	0.8702	0.5130	5.0889	0.3079	2.3027	2.5185	3.1388	1.6864	4.6237
	F ratio	57.908	53.90	778.39	116.7147	95254.7734	134.1050	609.4277	392.2313	113.0714	55.9087
	F Prob.	0.000	0.00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S.E.	0.520	0.714	0.203	0.1797	0.2549	0.1087	0.2402	0.0826	0.0676	0.7541
	C.D. 5%	1.465	2.011	2.574	2.5063	2.7178	1.3061	2.6765	2.2328	1.1904	2.1240
	C.D. 1%	1.944	2.66	2.762	2.6716	2.9522	1.4060	2.8974	2.3088	1.2526	2.8176
	Range Lowest	78.00	128.33	57.3000	3.6667	47.3333	4.5333	8.2933	2.8567	4.9667	17.1867
	Range Highest	98.66	151.66	81.7667	12.7667	387.3333	9.6000	31.1867	8.3600	8.8000	41.5067

Table-3: Analysis of variance for combining ability for different characters in linseed

S. No	**Mean sum of squares**				
	Characters	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

Table 4.1: 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**

Table 4.2: 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**

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

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
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**	-0.1	-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**
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	-0.8	-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**	0.1	-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	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*	0.1	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

Table 5: Heterosis (ha), Heterobeltiosis (h_b) and Economic Heterosis(hc) for different characters in linseed

	Genotypes	Plant height(cm)			Capsules per plant			Test weight (gm.)			Seed yield per plant (gm.)			Harvest index		
		Ha	Hb	Hc	Ha	Hb	Hc	Ha	Hb	Hc	Ha	Hb	Hc	Ha	Hb	Hc
1.	M-42(169) × FRW-6(973)	0.51	-1.27**	14.4**	21.9**	-5.3**	31.9**	-4.4**	-4.5**	-22.5**	28.1**	23.4**	63.2**	28.6**	17.9**	76.3**
2.	M-42(169) × C91538(456)	-10.2**	-15.1**	-1.6**	54.3**	41.3**	31.4**	-0.65	3.3*	-16.1**	-16.5**	-26.5**	-2.8	35.1**	23.4**	53.8**
3.	M-42(169) × POLF-19(1765)	-8.2**	-12.5**	1.4**	-15.2**	-27.8**	-44.2**	2.6**	0.0	-13.4**	92.2**	85.8**	145.7**	-0.3	-8.1**	35.8**
4.	M-42(169) × POLF-17(1704)	15.7**	6.38**	23.3**	6.2**	-0.48	-11.9**	-25.9**	-30.8**	-34.5**	-2.4**	-6.1*	24.3**	-20.7**	-23.5**	-4.6**
5.	M-42(169) × PbD2-42(2789)	-3.6**	-10.0**	4.3**	41.4**	9.9**	-15.1**	10.1**	4.3**	-4.2**	-16.8**	-30.5**	-8.1*	30.7**	16.8**	45.5**
6.	M-42(169) × GS-234(1703)	2.2**	-0.48**	15.3**	-19.5**	-34.3**	-49.2**	-16.1**	-23.1**	-24.1**	-16.6**	-29.3**	-6.5	48.6**	30.2**	62.3**
7.	M-42(169) × GS-129(1018)	10.5**	7.12**	24.1**	-30.4**	-31.1**	-45.6**	0.97	-1.3	-15.1**	-8.4**	-21.7**	3.5	-0.9	-4.6	18.9**
8.	FRW-6(973) × C91538(456)	2.7**	-1.18**	10.5**	107.3**	72.9**	140.7**	18.6**	15.5**	0.3	119.2**	99.5**	144.5**	-4.6	-19.5**	20.3**
9.	FRW-6(973) × POLF19(1765)	-3.3**	-6.20**	4.8**	61.6**	12.4**	56.4**	16.7**	13.8**	-1.4	81.7**	81.1**	123.5**	-13.3**	-5.9	40.5**
10.	FRW-6(973) × POLF17(1704)	-11.1**	-16.9**	-7.1**	101.8**	65.1**	129.8**	31.2**	22.4**	16.2**	20.4**	20.2**	47.4**	-9.4**	-19.5**	20.3**
11.	FRW-6(973) × PbD2-42(2789)	-3.98**	-8.9**	1.8**	64.4**	7.5**	49.7**	8.1**	2.3	-5.9**	45.1**	25.1**	53.4**	13.6**	-5.9	40.5**
12.	FRW-6(973) × GS-234(1703)	-4.1**	-4.9**	6.28**	51.1**	2.1**	42.1**	17.3**	7.5**	6.1**	82.1**	59.4**	95.4**	-25.8**	-39.6**	-9.8
13.	FRW-6(973) × GS-129(1018)	-9.6**	-10.8**	-0.30	-56.5**	-65.9**	-52.5**	6.9**	4.6**	-9.9**	80.5**	59.3**	95.3**	27.4**	12.9**	68.7**
14.	C91538(456)× POLF19(1765)	7.5**	6.6**	11.9**	185.3**	126.1**	110.3**	-0.2	-0.3	13.5**	14.7**	4.1	28.5**	-9.2**	-22.9**	13.9**
15.	C91538(456)× POLF17(1704)	-.53**	-3.5**	-0.30	110.9**	105.8**	91.5**	3.4**	-0.9	-6.1**	-8.8**	-16.9**	1.5	-2.9	-8.4	6.4
16.	C91538(456)× × PbD2-42(2789)	-7.06**	-8.4**	-5.5**	100.1**	46.2**	35.9**	-0.3	-3.1*	-10.9**	10.8**	4.3	4.8	51.1**	47.4**	51.8**
17.	C91538(456) × GS-234(1703)	3.5**	0.46	10.9**	196.4**	126.1**	110.3**	-6.1**	-11.6**	-12.9**	38.4**	32.6**	33.3**	-21.8**	-25.4**	-23.1**
18.	C91538(456) × GS-129(1018)	-3.10**	-5.5**	1.8**	6.2**	-1.8**	-8.7**	-3.1**	-3.5*	-16.2**	-2.4	-5.7	-5.2	13.2**	7.11	23.6**

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

	Genotypes	Plant height (cm)			Capsules per plant			Test weight (gm.)			Seed yield per plant (gm.)			Harvest index		
		Ha	Hb	Hc	Ha	Hb	Hc	Ha	Hb	Hc	Ha	Hb	Hc	Ha	Hb	Hc
19.	POLF-19(1765)× POLF-17(1704)	-11.9**	-15.2**	-10.9**	93.6**	56.3**	38.3**	8.5**	3.8**	-1.5	64.8**	64.1**	102.5**	10.6**	-1.3	45.9**
20.	POLF-19(1765)× PbD2-42(2789)	-0.8*	-3.1**	1.8**	191.9**	161.1**	41.9**	-14.5**	-16.9**	-23.7**	13.4**	-2.5	20.3**	-1.2	-17.8**	21.4**
21.	POLF-19(1765) × GS-234(1703)	-5.1**	-7.1**	2.1**	94.9**	85.0**	0.57	9.7**	3.1*	1.63	28.8**	12.4**	38.7**	21.3**	-0.8	46.6**
22.	POLF-19(1765) × GS-129(1018)	0.6	-1.1**	7.5**	160.6**	120.1**	73.6**	11.37**	11.03**	-3.8**	14.2**	0.50	24.1**	-23.7**	-32.1**	0.5
23.	POLF-17(1704)× PbD2-42(2789)	4.9**	3.3**	3.5**	55.3**	15.3**	1.9**	-0.05	-1.6	-6.7**	15.1**	-0.68	21.5**	0.18	-7.6	7.2
24.	POLF-17(1704) × GS-234(1703)	-8.5**	-13.8**	-5.4**	143.1**	88.6**	66.9**	1.8	-0.09	-1.5	16.2**	1.8	24.5**	76.9**	60.1**	85.7**
25.	PbD2-42(2789) × GS-234(1703)	-2.5**	-7.7**	0.3	55.9**	47.5**	30.5**	12.4**	7.2**	1.7	-11.2**	-21.5**	4.1	-7.8*	-8.1	6.8
26.	PbD2-42(2789) × GS-234(1703)	7.8**	3.1**	13.3**	9.1**	2.4**	-49.9**	4.1**	0.58	-0.84	22.6**	20.5**	10.8**	6.00	3.7	1.6
27.	PbD2-42(2789) × GS-129(1018)	-0.9*	-4.7**	3.5**	149.1**	92.2**	51.6**	5.84**	2.49	-5.85**	160.9**	154.1**	138.2**	23.1**	13.7**	31.3**
28.	GS-234(1703) × GS-129(1018)	-17.5**	-17.9**	-9.9**	90.2**	53.9**	21.5**	0.17	-6.2**	-7.5**	67.4**	65.8**	55.4**	19.2**	8.01**	24.7**

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

Harvest Index

The analysis of variance (ANOVA) for combining ability indicated that both general combining ability (GCA) and specific combining ability (SCA) significantly influenced the harvest index The GCA/SCA ratio for this trait was 0.08 (Table 5)., suggesting that non-additive genetic effects were the primary contributors to its genetic control. Significant heterosis was observed in several crosses, with the highest heterosis of 60.03% over the better parent in the hybrid POLF-17(1704) × GS-234(1703) (Table 5). Improving the harvest index in linseed cultivars is a key goal for breeders [10], and the substantial genetic variation observed for this trait in the current study offers promising opportunities for enhancing the harvest index in flax breeding programs.

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