Combining ability and heterosis for bud fly infestation and seed yield and it's attributes in linseed (*Linum usitatissimum* L.)

Dr. Rishi Pal

Associate Professor, (Agriculture), Meerut Institute of Technology Meerut (MIT), NH-58, Baral Partapur (U.P.)-India

Received:- 05 April 2025/ Revised:- 09 April 2025/ Accepted:- 18 April 2025/ Published: 30-04-2025
Copyright @ 2025 International Journal of Environmental and Agriculture Research
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0) which permits unrestricted Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

***Abstract*— *Four bud fly-resistant germplasm lines viz., EC-1424, GS-234, IC-15888, and JRF-5 were crossed with three testers (Neelum, Neela, and Shekhar) in a line × tester mating design to develop 21 F_1 and 21 F_2 crosses. The study was undertaken to estimate combining ability and heterosis in linseed (Linum usitatissimum L.) for bud fly infestation, seed yield, and related traits. The analysis of variance for general combining ability (GCA) and specific combining ability (SCA) was highly significant in both F_1 and F_2 generations.*

Based on per se performance and GCA effects, the best general combiners identified in both F_1 and F_2 generations were Neela for days to flowering and bud length; IC-15888 for sepal thickness, maturity duration, and bud fly infestation at the dough stage; Shekhar and Neela for grains per capsule; Neela for test weight; GS-234 and Neelum for oil content. However, no common general combiner was found for bud width, capsules per plant, and seed yield per plant across both generations. For capsules per plant, Shekhar was a good combiner only in the F_1 generation.

Heterosis over the superior parent for bud fly infestation at the dough stage ranged from –99.03% (EC-1424 × JRF-5) to –48.59% (Shekhar × Neelum) in the F_1 generation. Out of 21 crosses, 20 crosses exhibited significant negative economic heterosis for this trait. The top five promising crosses were EC-1424 × JRF-5, EC-1424 × Neela, GS-234 × IC-15888, GS-234 × JRF-5, and IC-15888 × Shekhar. Only one cross (EC-1424 × Shekhar) showed significant positive heterosis for bud fly infestation.

For seed yield per plant, heterosis over the economic parent ranged from 28.64% (JRF-5 × Neelum) to 51.90% (Shekhar × Neelum) in the F_1 generation. Among all crosses, six crosses exhibited significant positive heterosis. These cross combinations may serve as potential genetic resources in future linseed breeding programs aimed at improving yield and bud fly resistance.

***Keywords*— Combining ability, Heterosis Line × Tester, Linseed.**

I. INTRODUCTION

Linseed (*Linum usitatissimum* L.), commonly known as "Alsi", belongs to the genus *Linum* of the family Linaceae and has a chromosome number of 2n = 30. Globally, linseed is an important oilseed crop cultivated over an area of 27.29 lakh hectares, with a total production of 25.2 lakh tons and an average productivity of 923 kg/ha. In India, linseed is cultivated over 3.226 lakh hectares with a total production of 1.525 lakh tons, registering a comparatively low productivity of 473 kg/ha. India ranks third in terms of area under linseed cultivation, after Canada and China, but stands fifth in production following Canada, China, USA, and Ethiopia (Anonymous, 2013).

Continuous efforts towards yield improvement through hybridization and the selection of suitable parents are essential components of crop improvement programs. The line × tester mating design provides an effective method for precisely estimating the combining ability of parental lines and identifying superior parents and cross combinations. In this context, the present investigation was carried out to study the nature of combining ability and the extent of heterosis for yield, its contributing traits, and oil content in linseed

II. MATERIALS AND METHODS

The present experiment was conducted during *Rabi* 2020-21 at the Oilseed Research Farm, Kalyanpur, of Chandra Shekhar Azad University of Agriculture & Technology, Kanpur (U.P.). The experimental material comprised 49 genotypes, including 7 parents (4 lines and 3 testers), along with 21 F1 and 21 F2 progenies. The material was evaluated in a Randomized Complete Block Design (RCBD) with three replications.

Each genotype was sown in paired rows of 3 m length, maintaining a spacing of 30 cm between rows and 10 cm between plants. Observations were recorded on five randomly selected plants from each replication.

The data were recorded for eleven traits, namely: days to 5% and 90% flowering, flowering duration, number of bud fly maggots per 25 buds, bud fly infestation percentage at green bud stage and dough stage, bud shape (length and width), sepal thickness, flower colour, plant height, maturity duration, capsules per plant, seeds per capsule, test weight (g), seed yield per plant (g), and oil content (%).

The data were compiled and subjected to statistical analysis. Heterosis was estimated over the economic parent (Neelum), a commercial variety, while inbreeding depression (ID) in the F2 generation over F1 was estimated using the formulae given by Kempthorne (1957). Combining ability analysis was carried out following Griffing's (1956) Method 2, Model 1.

III. RESULT AND DISCUSSION

The mean sum of squares for all the characters are presented in **(Table-1)** Highly significant differences were recorded among all the treatments for all the 11 characters in both generations. The partitioning of treatments into parents and hybrids were also significant. Mean variances due to parents *viz* hybrid were also significant for majority of the characters. It indicated considerable variability with base material and material generated. Similar results were also reported by Singh *et al.* 1987, Thakur *et al.* 1987 and Khorgade *et al.* 1990.

Estimates of gca effects for 7 parents are presented in (**Table-2).** The highest positive and significant values of gca effects were considered desirable for the selection of good general combiners for all the characters except flowering duration, bud length, bud width, dough stage bud fly infestation and maturity period for which negative and significant values were desirable.

The gca and sca variances were highly significant both in F_1 and F_2 generations of the present study for all the characters except bud width in F_1 generation and oil content in F_2 which revealed that additive as well as non additive genetic effects were involved in the expression of these traits. However, additive effects were predominant for all the characters. Both gca and sca variances were found significant by Swarnkar *et al.* (2003) and Singh *et al.* (2004), Ratnaparkhi *et al.* (2005) and Singh *et al.* (2013).

The *per se* performance of parents was compared with their gca effects in F_1 and F_2 generations for all the characters under study. It was concluded that the parents having best *per se* performance were proved to be the best general combiners for almost all the characters. Chimurkar *et al.* (2001), Vishnu *et al. (*2005) and Kusalkar *et al.* (2003) also found almost similar results.

On the basis of *per se* performance and gca effects, the good general combiners common in both F_1 and F_2 generations were Neela for days to flowering, for bud length IC-15888, for sepal thickness IC-15888, for maturity duration Shekhar and Neela, for dough stage bud fly infestation % IC-15888, for Grain/capsules Neela, for test weight GS-234 and Neelum and for oil content Shekher. Not any general combiner was found common for character bud width, capsules/plant and yield/plant. For capsules/plant Shekhar only in F_1 generation. The consistency of combiners was stable. Stability for the important traits has been described as one of the important needs for breeding objectives.

The gca effects which included additive and additive x additive interactions (Griffing, 1956 and Sprague, 1966) represent fixable genetic variance (Gilbert, 1967). The additive parental effects measured by gca effects are of practical use. **(Table 3),** On the other hand, sca effects representing dominance and ecstatic components would not contribute much to the improvement of self pollinated crops except in cases where commercial exploitation of heterosis is feasible. Jinks and Jones (1958) further suggested that the superiority of many hybrids may not indicate their ability to produce transgressive segregants due to non-fixable genetic effects. Therefore, study of sca effects in segregating generations would be important.

TABLE 1
ANALYSIS VARIANCE FOR VARIOUS TRAITS OF LINSEED

Sources of variation	Generation	DF	Flowering duration (Days)	Bud length (mm)	Bud width (mm)	Sepal thickness (mm)	Maturity period (Days)	Dough stage bud fly infestation %	Capsules/ plant	Grains/ capsule	Yield/ plant (gm)	Test weight (1000) grains	Oil content %
Replicates	F_1	2	2.48	0.45	0.05	0.001	4.18	22.41	1000.33	0.107	5.40	0.05	0.54
	F_2	2	4.62	0.06	0.25	0.001	5.58	10.00	207.46	0.012	3.24	0.31	1.82
Treatments	F_1	27	25.14**	1.45**	0.31**	0.009**	129.28**	160.40**	4156.99**	2.791 **	19.82**	4.507 **	3.42**
	F_2	27	25.29**	1.34**	0.56**	0.008 **	132.69**	169.86**	3193.71**	2.594 **	19.63**	4.65**	4.33**
Parents	F_1	6	34.54**	3.12**	0.30*	0.02**	155.21**	437.10**	1084.89	2.714 **	10.11**	6.06 **	3.82*
Hybrids	F_1	20	22.40**	1.02**	0.31**	0.01**	126.93**	66.13**	2862.85**	2.938 **	14.54**	4.04 **	3.45**
	F_2	20	21.15**	0.87**	0.60**	0.01 **	132.36**	85.39**	1625.80**	2.354 **	9.93**	4.41**	4.69**
Parent Vs Hybrids	F_1	1	23.53*	0.05	0.53*	0.004*	20.57*	380.17**	48472.32**	0.321	183.8**	4.52 **	0.37
	F_2	1	52.48**	0.01	1.40*	0.001	4.06	250.56**	47204.77**	6.671 **	270.76**	0.80*	0.004
Error	F_1	54	5.39	0.40	0.10	0.001	4.03	9.23	643.36	0.416	2.01	0.13	1.41
	F_2	54	6.35	0.38	0.23	0.002	3.84	7.97	630.84	0.456	2.99	0.13	.1.44

NB: * and ** Significant at 5% and 1% level of significance, respectively

TABLE 2
GENERAL COMBINING ABILITY EFFECTS OF THE PARENTS FOR11 DIFFERENT TRAITS OF LINSEED

Source of variation	Generation	Flowering duration (Days)	Bud length (mm)	Bud width (mm)	Sepal thickness (mm)	Maturity period (Days)	Dough stage bud fly Infestation %	Capsules/ plant	Grains/ capsule	Yield/ plant (gm)	Test weight (1000) Grains	Oil content %
EC 1424	F_1	0.21	-0.15	-0.02	0.01	1.12**	-0.99	-7.61	-0.02	-0.48	-0.05	-0.51*
	F_2	0.28	-0.08	0.26**	-0.01	0.69	-2.18**	0.13	0.20	-0.22	-0.02	-0.52*
GS-234	F_1	0.02	0.26*	-0.08	-0.02**	-0.44	1.99**	-1.50	-0.28*	0.44	0.64**	-0.49*
	F_2	0.28	0.22	0.01	-0.00	-0.34	2.30**	2.099	-0.02	0.11	0.61**	-0.57*
IC-15888	F_1	-0.39	-0.36**	-0.01	0.04**	2.34**	-3.77**	2.46	-0.39**	-0.00	-0.32**	0.31
	F_2	-0.87	-0.28*	-0.12	0.04**	2.06**	-3.49 **	0.61	-0.43 **	-0.33	-0.20**	0.68**
JRF-5	F_1	0.95*	-0.15	-0.012	-0.01	2.38**	-0.80	3.68	0.24*	0.15	-0.40**	0.36
	F_2	1.31**	-0.29*	-0.01	-0.01	2.03**	-0.36	-6.87	0.02	-0.48	-0.68**	-0.16
Shekhar	F_1	-0.53	0.36**	0.06	0.00	-3.66**	0.42	9.76*	0.06	1.18**	0.40**	1.06**
	F_2	-0.50	0.18	-0.09	0.00	-4.09 **	-0.589	2.43	0.24	-0.43	-0.02	1.21**
Neelum	F_1	0.95*	0.02	0.04	-0.02 **	1.49**	3.98**	2.28	-0.05	-0.36	0.17**	-0.60**
	F_2	0.42	0.08	-0.06	-0.02*	2.58**	5.19**	3.58	-0.43 **	1.02**	0.37**	-0.59**
Neela	F_1	-1.20**	0.02	0.03	0.00	-3.22**	-0.82	-9.06	0.43**	-0.93 **	-0.44**	-0.14
	F_2	-0.91*	0.16	0.01	-0.01	-2.94 **	-0.87	-1.98	0.42**	0.34	-0.06	-0.05
CD 5%	F_1	1.01	0.28	0.14	0.01	0.89	1.32	11.06	0.28	0.62	0.15	0.52
CD 1%	F_1	1.53	0.42	0.21	0.02	1.33	2.01	16.76	0.43	0.94	0.23	0.79
CD 5%	F_2	1.10	0.27	0.21	0.02	0.86	1.23	10.95	0.30	0.75	0.16	0.52
CD 1%	F_2	1.66	0.41	0.31	0.03	1.30	1.86	16.59	0.45	1.14	0.24	0.79

NB: *, and ** Significant at 5% and 1% level of significance, respectively

TABLE 3
ESTIMATES OF SCA EFFECTS FOR VARIOUS CHARACTERS IN F1 AND F2 CROSSES IN LINSEED

S.N.	Hybrid combination	Generation	Flowering duration (Days)	Bud length (mm)	Bud width (mm)	Sepal thickness (mm)	Maturity period (Days)	Dough stage bud fly infestation%	Capsules/ plant	Grains/ capsule	Yield/ plant (gm)	Test weight (1000) grains	Oil content %
			sca effect	sca effect	sca effect	sca effect	sca effect	sca effect	sca effect	sca effect	sca effect	sca effect	sca effect
1	EC-1424×GS-234	F_1	-1.97	-1.10**	-0.2	0.07**	4.11**	-6.24**	-22.49	0.23	-1	-0.84**	-0.36
		F_2	-1.95	-0.42	0.06	0.06**	0.59	-6.47**	23.34	-0.44	2.65**	0.42*	-0.19
2	EC-1424× IC-15888	F_1	-1.64	-0.62	-0.2	0.05**	-1.11	-11.23**	69.36**	0.94*	2.74**	-0.14	-0.04
		F_2	-2.36	-1.10**	-0.59*	0.09**	-1.59	-9.70**	15.27	-1.25**	-1.07	-1.25**	1.43*
3	EC-1424× JRF-5	F_1	2.88*	-0.39	-0.35*	0.01	-1.11	-8.55**	28.66*	-0.95**	-0.93	-1.39**	-0.41
		F_2	-0.99	-0.74*	-0.37	0.02	-4.41**	-9.14**	33.75*	0.42	2.92**	0.94**	0.05
4	EC-1424× Shekhar	F_1	-2.12	0.74*	0.64**	-0.02	-4.15**	-3.80*	-14.9	0.58	-1.167	-0.23	0.44
		F_2	-1.84	0.52	-0.11	-0.01	-2.37*	-1.8	-27.44*	-1.36**	-1.06	-1.43**	-0.43
5	EC-1424× Neelum	F_1	-1.86	-0.13	0.14	-0.03	-2.33*	0.02	-10.38	-0.73*	-1.44	-1.41**	-0.02
		F_2	-2.14	0.18	0.18	0.02	2	-0.16	10.94	-0.32	2.70**	0.28	-0.14
6	EC-1424× Neela	F_1	-3.05*	-0.12	-0.46*	0	-2.89*	-8.10**	9.4	-0.32	0.37	-0.45*	0.05
		F_2	-1.47	0.23	-0.19	-0.05*	3.63**	-4.41**	7.9	0.79*	-0.95	-2.16**	-1.26
7	GS-234 × IC-15888	F_1	-0.49	0.06	0.08	0.06**	1.59	-5.46**	-13.64	0.12	-0.37	-1.57**	-0.46
		F_2	-1.36	-0.22	-0.07	0.02	2.59*	-3.57*	-5.18	0.23	0.61	-1.65**	-0.31
8	GS-234 × JRF-5	F_1	-1.31	0.04	-0.15	0.03	-6.41**	-0.8	2.32	0.90*	0.48	-0.11	-0.11
		F_2	-0.32	-0.55	-0.5	0.01	-0.89	-3.63*	2.97	0.57	0.26	-0.40*	-0.55
9	GS-234 × Shekhar	F_1	-1.31	-0.26	0.04	-0.04*	-4.44**	2.99	19.44	-2.07**	1.02	0.50*	1.6
		F_2	-3.18*	0.25	0.16	-0.04*	-4.85**	1.2	-8.55	-0.21	0.49	-0.37	0.53
10		F_1	-2.05	-0.48	-0.36*	-0.05**	0.7	0.39	4.95	0.79*	0.06	-0.12	-0.23
	GS-234 × Neelum	F_2	-1.14	-0.18	-0.25	-0.03	-0.48	5.66**	44.16**	0.49	2.78**	0.65**	-0.17

11	**GS-234 × Neela**	F_1	-1.23	0.26	0.28	0.01	-3.85**	-0.3	71.73**	0.53	1.48	-0.15	-0.42
		F_2	-0.14	0.28	0.05	0.01	-3.19**	-1.46	32.79*	0.6	1.04	1.06**	0.84
12	**IC-15888× JRF-5**	F_1	-2.31	-0.13	0.28	-0.02	-3.96**	-0.96	57.84**	-0.73*	3.66**	0.86**	-0.87
		F_2	-0.4	-0.42	-0.28	-0.01	-4.41**	-3.88*	27.57*	-0.58	0.09	-0.58**	-0.26
13	**IC-15888× Shekhar**	F_1	-1.64	0.06	-0.03	-0.02	-3.00**	-5.75**	-3.71	-0.03	0	-0.72**	0.85
		F_2	-2.58	0.89*	0.44	-0.01	-2.70*	-1.58	2.05	0.64	-1.07	-0.08	-0.19
14	**IC-15888× Neelum**	F_1	-1.38	0	0.38*	0.06**	0.15	0.93	19.81	-1.51**	1.25	0.76**	-0.29
		F_2	-1.88	-0.42	-0.42	-0.04	1.67	-3.32*	-3.58	1.34**	-1.5	-0.40*	-0.12
15	**IC-15888× Neela**	F_1	-2.90*	0.28	-0.44*	-0.01	-1.74	-1.29	-24.75	0.23	-1.70*	-0.74**	0.97
		F_2	-2.55	0.29	0.2	0.07**	-4.37**	-4.33**	38.38**	0.12	3.16**	1.19**	-0.05
16	**JRF-5× Shekhar**	F_1	1.21	0.65	-0.03	-0.05**	5.67**	3.62*	6.25	1.08**	-0.48	-1.24**	0.88
		F_2	2.12	0.49	-0.17	-0.04*	8.82**	6.60**	37.19**	0.97*	0.18	-0.76**	0.95
17	**JRF-5× Neelum**	F_1	2.14	-0.5	-0.61**	-0.07**	13.82**	0.05	51.10**	1.94**	2.27**	-0.44*	0.11
		F_2	2.82*	0.98**	0.57*	0.02	12.52**	9.25**	23.57	0.68	1.31	-0.21	-0.77
18	**JRF-5× Neela**	F_1	2.29	-0.72*	-0.04	0.04*	9.93**	2.61	-21.12	-0.32	1.03	-0.32	0.07
		F_2	-1.18	-0.41	-0.76**	-0.05*	6.12**	-0.76	-8.47	0.45	1.06	-0.70**	1.48*
19	**Shekhar× Neelum**	F_1	2.14	0.92*	0.25	-0.01	-5.89**	7.33**	19.21	-0.03	4.31**	1.37**	0.24
		F_2	2.97*	-0.52	-0.33	-0.01	-8.79**	1.27	4.05	-0.77*	2.83**	1.16**	0.93
20	**Shekhar× Neela**	F_1	1.95	0.93*	0.06	-0.03	-6.11**	1.99	9.66	1.38**	1.86*	1.83**	-0.69
		F_2	3.30*	0.95**	0.79**	-0.04*	-8.48**	3.84*	-14.66	0.34	2.75**	2.33**	-0.8
21	**Neelum× Neela**	F_1	6.21**	0.22	-0.25	-0.05**	5.05**	6.78**	32.51	-0.1	4.49**	1.74*	-0.55
		F_2	4.68**	-0.13	-0.01	-0.04*	5.89**	5.44**	51.38**	0.713	2.60**	0.78**	-1.05
Sij	**CD 5%**	F_1	2.51	0.68	0.35	0.03	2.17	3.28	27.42	0.7	1.53	0.38	3.76
	CD 1%	F_1	3.42	0.93	0.48	0.05	2.97	4.48	37.4	0.95	2.09	0.52	5.13
Sij	**CD 5%**	F_2	3.72	0.67	0.51	0.04	2.12	3.05	27.15	0.73	1.87	0.39	1.3
	CD 1%	F_2	4.05	0.91	0.7	0.06	2.89	4.16	37.03	0.1	2.55	0.53	1.77

NB: * and ** Significant at 5% and 1% level of significance, respectively

TABLE 4
ESTIMATES OF HETROSIS (%) OVER ECONOMIC PARENT OF YIELD COMPONENTS IN LINSEED 2020-21

S.No.	Characters'	Flowering duration (Days)	Bud length (mm)	Bud width (mm)	Sepal thickness (mm)	Maturity period (Days)	Dough stage bud fly infestation%	Capsules/ plant	Grains/ capsule	Yield/ plant (gm)	Test weight (1000) Grains	Oil content %
	Crosses F1	**EH**	**EH**	**EH**	**EH**	**EH**	**EH**	**EH**	**EH**	**EH**	**EH**	**EH**
1	**EC-1424×GS-234**	-38.09**	-21.72**	-11.5	48.27**	-3.18*	-79.17**	-3.84	0	-24.2	-37.89**	-0.14
2	**EC-1424× IC-15888**	-33.33**	-12.51*	-10.68	41.37**	-7.35**	-89.09**	102.9**	4.12	37.73*	-22.03**	4.2
3	**EC-1424× JRF-5**	-11.09	-17.97**	-16.98	41.37**	-2.94*	-99.03**	57.56**	-25.00**	-13.53	-42.32**	0.97
4	**EC-1424× Shekhar**	-28.57**	-2.84	10.13	13.79	-5.14**	72.67**	15.76	-12.5	-14.37	-31.10**	3.57
5	**EC-1424× Neelum**	-31.76**	-7.96	-5.2	6.89	-5.88**	-55.25 **	15.11	-20.87**	-14.27	-32.64**	-0.2
6	**EC-1424× Neela**	-36.52**	-12.51	-19.72**	31.03**	-5.14**	-84.54 **	28.3	-12.5	-4.86	-29.86**	-0.05
7	**GS-234 × IC-15888**	-38.09**	-4.89	-3.28	55.17**	-8.82**	-86.55 **	11.9	0	-1.26	-43.04**	4.35
8	**GS-234 × JRF-5**	-42.28**	-13.19*	-11.5	55.17**	-10.29**	-85.25 **	20.66	4.12	-4.75	-35.42**	1.49
9	**GS-234 × Shekhar**	-34.90**	-14.33*	-6.57	13.79	-8.82**	-67.44 **	37.95	-25.0**	2.64	-29.86**	8.26**
10	**GS-234 × Neelum**	-42.85**	-12.05*	-19.17*	6.89	-7.10**	-66.92 **	18.97	4.12	-4.54	-25.54**	-0.54
11	**GS-234 × Neela**	-38.09**	-8.3	0	37.93**	-9.31**	-76.60 **	77.50**	4.12	0.84	-33.05**	-.0.05
12	**IC-15888× JRF-5**	-42.85**	-11.26	1.09	41.37**	-8.82**	-82.45 **	91.97**	-20.87**	51.16**	-16.88**	4.43
13	**IC-15888× Shekhar**	-33.33**	-6.71	-7.39	20.68*	-8.08**	-87.29 **	33.77	-4.12	14.16	-33.82**	9.56**
14	**IC-15888× Neelum**	-38.09**	-2.73	1.91	44.82**	-8.08**	-62.31 **	51.45*	-29.12**	30.33*	-8.03*	3.83
15	**IC-15888× Neela**	-42.85**	-4.32	-18.35*	31.03**	-8.08**	-76.01 **	2.57	-4.12	-10.46	-30.48**	7.37*
16	**JRF-5× Shekhar**	-19.04*	-8.19	-9.31	27.58*	2.69*	-73.56 **	36.02	4.12	-3.38	-46.65**	7.46**
17	**JRF-5× Neelum**	-19.04*	-16.49**	-27.39**	13.79	6.61**	-75.61 **	74.60**	8.37	28.64*	-27.70**	2.79
18	**JRF-5× Neela**	-19.04*	-23.66**	-9.58	62.06**	4.41**	-76.74 **	-0.95	-16.62*	5.81	-33.67**	2.62
19	**Shekhar× Neelum**	-12.71	2.04	-3.83	17.24	-8.08**	-48.59 **	45.02*	-8.37	51.90**	-9.88**	3.34
20	**Shekhar× Neela**	-12.71	-1.47	-7.39	20.68*	-6.86**	-70.64**	29.91	0	16.27	-11.22**	0.31
21	**Neelum× Neela**	3.19	-5.91	-17.26	10.34	-0.73	-50.52**	46.95*	-12.5	47.07**	-2.47	-1.41
	SE (d)	1.896	0.574	0.263	0.0256	1.642	2.48	20.71	0.526	1.157	0.288	0.963
	CD 5%	3.831	1.042	0.533	0.0516	3.318	5.012	41.855	1.046	2.338	0.582	1.963
	CD 1%	5.127	1.39	0.711	0.069	4.44	6.706	56	1.422	3.129	0.779	2.626

NB: * and ** Significant at 5% and 1% level of significance, respectively

For dough stage bud fly infestation % 10 cross combinations in F_1 and 14 in F_2 generation were found desirable with highly significant sca effects. Relatively higher estimates of sca effects were usually recorded in those crosses which involved diverse interacting parents. Swarnkar *et al. (*2003), Vishnu *et al. (*2005) also Tripathi *et al.* (2011) reported corroborative findings.

EC-1424×GS-234, EC-1424× IC-15888, EC-1424 × JRF-5, EC-1424 × Neela, JRF-5×Shekhar and Neelum ×Neela in both the generations had desirable significant sca effects which are indicative of the presence of additive x additive interaction effects. Similar results were also reported by Singh *et al.* (2013).

Heterotic response has often been expressed as a deviation of F_1 from the economic parental value (high yielding and well adopted cultivar) or superior parent. The degree of heterosis should preferably be measured as superiority of F_1 hybrids over the best commercial variety **(Table 4).** Such estimate, in real sense, decides whether the hybrid is worth exploiting or not.

The degree and direction of heterosis response varied not only from character to character but also from cross to cross. In the present investigation, character shows dough stage bud fly infestation shows heterosis over superior parent ranged from –99.03 (EC-1424× JRF-5) to -48.59 (Shekhar×Neelum) in F_1 generation. Out of 21 crosses 20 crosses showed negative significant economic heterosis. The best five crosses are EC-1424× JRF-5, EC-1424× Neela, GS-234 × IC-15888, GS-234×JRF-5 and IC-15888×Shekhar. Only one cross showed positive significant (EC-1424× Shekhar). In seed yield per plant shows the heterosis over economic parent ranged from 28.64 (JRF-5×Neelum) to 51.90 (Shekhar×Neelum) in F_1 generation. In all crosses, six cross as showed positive and significant heterosis. The best two crosses were observed (Shekhar×Neelum and IC-15888×JRF-5). Similar results were also reported by Kumar and Singh (2002).

In sepal thickness character, 14 crosses showed positive and significant hetrosis crosses. In days to maturity character, significant and negative economic heterosis was found in 17 crosses. Similar results were also reported by Sharma *et al.* (2000) and Sharma *et al.* (2005). In Capsule/plant character, 8 crosses showed positive and significant hetrosis. Similar results were also reported by Kusalkar *et al.* (2002) and Kumar and Singh (2002).

In grain per capsule character, the significant and negative economic heterosis were found EC-1424×JRF-5, EC-1424×Neelum, GS-234×Shekhar, IC-15888×JRF-5, IC-15888× Shekhar and JRF-5×Neela and six crosses IC-15888×Neelum, EC-1424×JRF-5, EC-1424×Neela, GS-234×Shekhar, JRF-5×Neela and Neelum×Neela. Similar results were also reported by Singh *et al.* (2005).

In 1000-seed weight, 20 crosses were found significant and negative economic heterosis. Similar results were also reported by Sharma *et al.* (2005).

In oil content character, only four crosses (GS-234×Shekhar, IC-15888×Shekhar, IC-15888×Neela and JRF-5×Shekhar) showed positive and significant heterosis. Similar results were also reported by Ratnaparkhi *et al.* (2005) and Singh *et al.* (2005).

IV. CONCLUSION

Combining ability analysis was carried out in linseed during *rabi* 2020-21. The experimental material included in present study consisting 49 genotypes comprising 7 parents and 21 F_1 and 21 F_2. The study revealed the importance of non-additive gene action in the inheritance of all the traits and stresses the need for its exploitation either through heterosis breeding or suitable population improvement programme.

On the basis of *per se* performance and gca effects good general combiners common in both F_1 and F_2 generations were Neela for days to flowering and bud length, IC-15888, sepal thickness, maturity duration and Grain/capsules. Shekhar and Neela, for dough stage bud fly infestation %, Neela, for test weight GS-234 and Neelum and for oil content Shekher. The best five crosses are EC-1424× JRF-5, EC-1424× Neela, GS-234 × IC-15888, GS-234×JRF-5 and IC-15888×Shekhar. Only one cross showed positive significant (EC-1424× Shekhar). In seed yield per plant shows the heterosis over economic parent ranged from 28.64 (JRF-5×Neelum) to 51.90 (Shekhar×Neelum) in F_1 generation. In all crosses, six cross as showed positive and significant heterosis. These crosses combinations could be utilized for further use in breeding programme for improvement in yield of linseed.

REFERENCES

[1] Anonymous 2013. Annual report of Linseed: 2012-13, Publ. Project Coordinating Unit (Linseed), C. S. Azad University of Agriculture & Technology, Kanpur. Executive Summary, i.

[2] Bhateria, S., Sood, S. and Pathania, A. 2006. Genetic analysis of quantitative traits across environments in linseed (*Linum usitatissimum* L.). *Euphytica*. 150(1-2): 185-194.

[3] Cockerham, C. C. 1961. Implication of genetic variance in a hybrid breeding programme. Crop Sci. 1: 47-52.

[4] Dakhore, S. R., Narkhede, M. N. and Khargade, P. W. 1987. Heterosis in relation to combining ability effects in linseed (*Linum usitatissimum* L.). PKV Res. J. 11(1): 7-12.

[5] Foster, R., Pooni, H. S. and Mackay, I. J. 1998. Quantitative analysis of *Linum usitatissimum* L. crosses for dual purpose traits. J. Agric. Sci. 131(1): 285-292.

[6] Gauraha, D., Rao, S. S. and Pandagare, J. M. 2011. Genetic analysis of yield and yield attributing characters in linseed (*Linum usitatissimum* L.). Asian J. Bio Sci. 6(1): 16-22.

[7] Hayes, H. K., Immer, F. F. and Smith, D. C. 1956. Methods of Plant Breeding. McGraw Hill Book Publishing Company, Inc., New Delhi.

[8] J. and Meena, H. P. 2013. Heterosis and combining ability for yield and yield component characters of newly developed castor (*Ricinus communis* L.) hybrid. The Bioscan. 8(4): 1421-1424.

[9] Jain, A. and Rao. S. S. 2004. Study of combining ability by diallel cross analysis in linseed (*Linum usitatissimum* L.). J. Agril. Issues. 9(1&2): 109-111.

[10] Jhajharia, S., Choudhary, P., Jhajharia, A., Meena, L.K. and Singh, D. 2013. Heterosis and combining ability in safflower (Carthamus tinctorius L.) germplasm lines. The Bioscan. 8(4): 1453-1460.

[11] Kansal, K. K. and Gupta, S. C. 1981. Note on heterosis in linseed. Indian J. Agric. Sci. 51(9): 680-687.

[12] Kempthorne, J. W. 1957. An introduction to genetic studies (Ed.) J. Wiley and Sons, Inc. New York, USA.

[13] Khorgade, P. W., Narkhede, M. N., Ingle, W. S., Raut, S. K. and Dakhore, S. R. 1990. Combining ability for yield, oil content and related components in linseed. *J. Maharashtra Agric. Univ*. 15(3): 281-283.

[14] Khorgade, P. W., Sakhre, B. A., Narkhede, M. N. and Raut, S. K. 1993. Genetic analysis of seed yield and its attributes in linseed. Biovigyana. 19(1-2): 7-10.

[15] Kurt, O. and Evans, G. M. 1998. Genetic basis of variation in linseed (*Linum usitatissimum* L.) cultivars. Turkish J. Agric. For. 22(4): 373- 379.

[16] Mishra, R. K., Marker, S., Bhatnagar, V. and Mahto, D. 2013. Combining ability and heterosis for seed yield and its component in linseed (*Linum usitatissimum* L.). Adv. Plant Sci. 2(1): 44-47.

[17] Ramesh, M., Lavanya, C., Sujatha, M., Sivasankar, A., Aruna Kumari, and applications; Short Communications, Symposium; Ludhiana, pp. 52-53.

[18] Rao, S. K., Singh, S. P. and Tawar, M. L. 1987. Heterosis for seed size and oil content in linseed. J. Oilseeds Res. 4(2): 242-245.

[19] Rao, S. S. and Rastogi, N. K. 2007. Combining ability for seed yield and its attributes in linseed (*Linum usitatissimum* L.). J. Oilseeds Res. 24(1): 68-71.

[20] Ratnaparkhi, R. D., Dudhe, M. Y., Gawande, N. D. and Bhongle, Reddy, M. P., Arsul, B.T., Shaik, N. R. and Maheshwari, J. J. 2013. Estimation of heterosis for some traits in linseed (*Linum usitatissimum* L.). J. Agri and Vet. Sci. 2(5): 11-17.

[21] Rede, A. P. 1999. Genetic analysis of yield and yield attributing characters in linseed (*Linum usitatissimum* L.). M.Sc. Thesis, Indira Gandhi Krishi Vishwavidyalaya, Raipur, C.G.

[22] S.A. 2005. Combining ability study in linseed through line × tester analysis. Ann. Plant Physiol. 19(1): 99-102.

[23] Saraswat, A. V., Kumar, S., Kumar, S., Verma, M. M., Virk, D. S. and Chahal, G.S. 1993. Heterosis and inbreeding depression in some early hybrids of linseed. Heterosis breeding in crop plants- theory and applications; Short Communications, Symposium; Ludhiana, pp. 52-53.

[24] Sharma, R., Tiwari, S. K., Singh, P. and Kant, R. 2005. Heterobeltiosis and inbreeding depression in linseed. Agric. Sci. Digest. 25(1): 35- 37.

[25] Singh, P. K., Srivastava, R. L., Narain, V. and Dubey, S. D. 2009. Combining ability and heterosis for seed yield and oil content in linseed *(Linum usitatissimum* L.). Indian J. Agri. Sci. 79(3): 229-232.

[26] Singh, R. K. and Chaudhary, B. D. 1977. Biometrical methods in quantitative genetic analysis. Kalyani Publishers, Ludhiana.

[27] Singh, R. S., Singh, S. and Chaudhary, R. K. 1983. Heterobeltiosis in relation to per se performance and effects of general combining ability in linseed (*Linum usitatissimum* L.). Pre-congress Scientific meeting on genetics and improvement of heterotic systems, Tamil Nadu Agril. Uni., Coimbatore.

[28] Singh, V., Chauhan, M. P., Kumar, K. and Singh, R. B. 2006. Heterosis for yield and yield attributes in linseed (*Linum usitatissimum* L.). Farm Sci J. 15(1): 29-31.

[29] Singh, V., Pachauri, O. P. and Tiwari, S. N. 1987. Combining ability studies in linseed (*Linum usitatissimum* L.). Indian J. Genet. 47(2): 171-178.

[30] Srivastava, R. L., Srivastava, S. K., Dubey, S. D. and Kerkhi, S. A. 2004. Heterosis and combining ability estimates in linseed under salt affected soil. Indian Agric. 48(3&4): 193-197.

[31] Tak, G. M. and Gupta, V. P. 1993. Studies on heterosis in linseed. Indian J. Agri. Res. 27(4): 181-184.

[32] Thakur, H. L., Rana, H. D. and Sood, O. P. 1987. Combining ability analysis for some quantitative characters in linseed. Indian J. Genet. 47(1): 6-10.

[33] Verma, A. K. and Mahto, J. L. 1996. Hybrid vigour in linseed (*Linum usitatissimum* L.) for yield and its attributes under rainfed and irrigated environments. J. Tropical Agri. 34(1): 54-57.