The Pharma Innovation Journal 2021; 10(10): 2265-2270

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2021; 10(10): 2265-2270
© 2021 TPI
www.thepharmajournal.com
Received: 05-08-2021
Accepted: 09-09-2021

The study of heterosis and inbreeding depression for seed yield and its attributes in linseed (*Linum usitatissimum* L.)

Shanti Bhushan, Sanjay Kumar, Sunil Kumar, Vinay Kumar Choudhary, Anuj Kumar Choudhary and Sohan Ram

Shanti Bhushan
Department of Plant Breeding and Genetics, VKSCOA (BAU, Sabour), Dumraon, Buxar, Bihar, India

Sanjay Kumar
Department of Plant Breeding and Genetics, MBAC (BAU, Sabour), Agwanpur, Saharsa, Bihar, India

Sunil Kumar
Department of Plant Breeding and Genetics, VKSCOA (BAU, Sabour), Dumraon, Buxar, Bihar, India

Vinay Kumar Choudhary
Tirhut College of Agriculture (RPCAU, Pusa), Dholi, Muzaffarpur, Bihar, India

Anuj Kumar Choudhary
Department of Plant Breeding and Genetics, BPSAC (BAU, Sabour), Purnea, Bihar, India

Sohan Ram
Department of Plant Breeding and Genetics, RAC (BAU, Kanke), Ranchi, Jharkhand, India

Corresponding Author:
Shanti Bhushan
Department of Plant Breeding and Genetics, VKSCOA (BAU, Sabour), Dumraon, Buxar, Bihar, India

Abstract
Heterosis and inbreeding depression for seed yield and yield attributes was studied in eight diverse linseed genotypes and one check under normal environmental condition. The analysis of variance in complete randomized block design for nine genotypes revealed significant differences among nine genotypes for all the ten characters indicating the sufficient amount of genetic variability present in experimental material, except number of primary branches per plant. Significant and desirable heterosis over mid parent was observed in four crosses for days to 50% flowering, two crosses for days to maturity, three crosses for plant height, two crosses for number of primary branches per plant, twelve crosses for number of capsules per plant, three crosses for number of seeds per capsule, seven crosses for capsule diameter, twelve crosses for each seed yield per plant and 1000-seed weight and eleven crosses for oil content. Heterosis over better parent it was observed significant and in desirable direction for seven crosses for days to 50% flowering, five crosses for days to maturity, four crosses for plant height, two crosses for number of primary branches per plant, nine crosses for number of capsules per plant. Similarly, heterosis over check variety T-397 was found significant desirable in eleven crosses for number of capsules per plant, thirteen crosses for each capsule diameter, seed yield per plant and oil content all the fifteen crosses for 1000-seed.
Inbreeding depression in F_2 generation showed that only one cross for days to 50% flowering, three crosses for days to maturity, two crosses for plant height, three crosses for number of primary branches per plant, eight crosses for number of capsules per plant, two crosses for number of seeds per capsule, twelve crosses for capsule diameter, eleven crosses for seed yield per plant, ten crosses for 1000-seed weight and nine crosses for oil content revealed significant positive inbreeding depression.

Keywords: Linseed, heterosis, heterobeltiosis, inbreeding depression

Introduction
Linseed (*Linum usitatissimum* L.) is the sixth largest oilseed crop in the world and is one of the oldest cultivated plants (Bhatty and Rowland, 1990) [3]. It is grown for linen fiber, the earliest vegetable fiber domesticated by mankind, and as an oilseed (Dillman, 1938; Richharia, 1962) [5].

Linseed (*Linum usitatissimum* L.), an important oilseed crop belonging to Linaceae family, with 14 genera and over 200 species is the only species in this family with economic and agronomic values (Tadesse *et al.*, 2009) [27]. It is a self-pollinated crop but cross pollination occurs up to 2% (Tadesse *et al.*, 2009) [27]. Every part of the linseed plant is utilized either directly or after processing. It is used as food (dietary fibres, micronutrients and omega -3 fatty acids), feed (oil cakes) and contains medicinal properties like antioxidant, phytoestrogen and anti-cancerous (Touré and Xueming, 2010) [29] and (Chopra and Badiyala, 2016) [4]. It also has a huge industrial demand for its fibre (flax and linen) and oil (paint, lubricant and varnish). It is generally unsuitable for culinary purpose due to high linolenic acid content (47-58 per cent) but it is an excellent source for industrial purposes.

Globally, linseed is grown in an area of 32.63 lakh ha yielding 31.82 lakh tones with an average productivity of 975 kg per hectare (Anonymous, 2019) [1]. Canada is currently the world's leader in the production and export of flax seed, a position it has held since 1994. In India, it occupies an area of 1.8 lakh ha with production and productivity 1.1 lakh tonnes of and 671 kg/ha respectively. Four states *viz*. Madhya Pradesh, Jharkhand, and Odisha are the major linseed growing states accounting for 65% of area and 64% of production, respectively. (Anonymous, 2020) [2].

Apart from other methods to realize the yield potential in linseed, heterosis can be exploited as it has been successfully used in various self-pollinated crops.The magnitude of heterosis provides a basis for genetic diversity and guideline to the choice of desirable parents for developing superior F_1 hybrids so as to exploit hybrid vigour and for building gene pool to be exploited in population improvement. Therefore, heterosis studies can provide the basis for the exploitation of valuable hybrid combinations in future breeding programs as earlier reported by Pali and Mehta (2014) [15]; Reddy *et al.*, (2013) [18].

Materials and Methods

The present investigation was carried out at the experimental area of Plant Breeding and Genetics Department, Ranchi Agricultural College, Birsa Agricultural University, Ranchi during *Rabi*, 2014 to Rabi, 2016. Nine diverse parents namely Chambal, Nagarkot, Janki, Rashmi, Mukta, BAU-13-2, SLS-61, Meera and T-397 as check were selected and crossed for generation mean analysis. Fifteen F_1's were developed during *Rabi*, 2014-15 *viz*.; Cross-I (Chambal x BAU-13-1), Cross-II (Nagarkot x BAU-13-1), Cross-III (Janki x BAU-13-1), Cross-IV (Rashmi x BAU-13-1), Cross-V (Mukta x BAU-13-1), Cross-VI (Chambal x SLS-61), Cross-VII (Nagarkot x SLS-61), Cross-VIII (Janki x SLS-61), Cross-IX (Rashmi x SLS-61), Cross-X (Mukta x SLS-61), Cross-XI (Chambal x Meera), Cross-XII (Nagarkot x Meera), Cross-XIII (Janki x Meera), Cross-XIV (Rashmi x Meera) and Cross-XV (Mukta x Meera). In next year *Rabi*, 2015-16, available F_1's were advanced to get F_2 seeds and simultaneously fresh F_1's were also made In *Rabi*, 2016, nine parents along with their resulting 15 F1's and 15 F_2's were evaluated under rainfed condition with three replications in complete randomized block design with a spacing of 30 cm and 10 cm between and within the rows respectively. Non-experimental rows were planted all around the experiment to eliminate the border effects, if any. All recommended agronomical package of practices were adopted to raise good crop. Observations were recorded on days to 50% flowering, days to maturity, plant height, number of branches per plant, number of capsules per plant, number of seeds per capsule, capsule diameter, seed yield per plant, 1000-seeds weight and oil content.

Standard heterosis over check varieties (T-397) was calculated as per formula Meredith and Bridge (1972) [14], heterobeltiosis was calculated following the method Fonseca and Patterson (1968) [6] and mid-parent heterosis (relative heterosis) was found out by the process suggested by Turner (1953) [30]. The cause of decrease in fitness and vigour *i.e*. Inbreeding depression was estimated in per cent with the help of F_1 and F_2 populations of the each fifteen crosses.

Results and Discussion

The analysis of variance in complete randomized block design for non-segregating genotypes that is parents and check also revealed significant differences among nine genotypes for all the ten characters except number of primary branches per plant (Table-1). The expression of heterosis in percentage over mid parent (relative heterosis), over better parent (heterobeltiosis) and over economic check variety (economic or standard or useful heterosis) as well as estimates of inbreeding depression of fifteen crosses were studied for ten characters and have been given in Table-2.

Table 1: Analysis of variance (MSS) for different yield and yield attributing characters in linseed for non-segregating genotypes (parents and check)

Source of variation	df	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of primary branches per plant	No. of capsules per plant	No. of seeds per capsule	Capsule diameter (mm)	Seed yield per plant (g)	1000-seed weight (g)	Oil content (%)
Replications	2	12.48	6.00	26.96	0.04	1.04	1.33	0.00	0.19	0.00	0.69
Genotypes	8	71.95**	118.00**	199.18**	2.95	1747.56**	2.00**	0.66**	4.69**	3.39**	263.35**
Error	16	3.98	1.75	7.59	1.16	254.49	0.37	0.002	0.72	0.00	0.61

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

Table 2: Estimates of heterosis (MP, BP and Check) and inbreeding depression in per cent for days to 50 per cent flowering, days to maturity and plant height in linseed

Cross No	Hybrid combinations	Days to 50% flowering				Days to maturity				Plant height (cm)			
		MP	BP	Check	ID	MP	BP	Check	ID	MP	BP	Check	ID
Cross-I	Chambal X BAU-13-1	0.85	-1.65	4.85*	2.52	-0.25	-3.35**	9.19**	1.24	-2.77	-5.88	10.15	-19.20**`
Cross-II	Nagarkot X BAU-13-1	1.64	-3.88*	9.25**	-4.84**	4.31**	0.71	14.59**	3.77**	-1.48	-5.41	12.60*	-6.11
Cross-III	Janki X BAU-13-1	2.29	-1.99	8.37**	-7.32**	1.60*	-1.90*	11.62**	-1.69	-1.33	-1.89	7.48	-1.23
Cross-IV	Rashmi X BAU-13-1	-4.29**	-9.65**	3.08	-4.70*	0.00	-4.42**	11.08**	-4.38**	-13.73**	-22.19**	6.03	-24.07**
Cross-V	Mukta X BAU-13-1	-3.64*	-5.06**	-0.88	-8.89**	1.24	-1.68	10.54**	-8.31**	-6.36	-6.66	2.26	-9.04
Cross-VI	Chambal X SLS-61	2.40	-2.89	3.52	-4.26*	-0.83	-1.19	12.43**	4.33**	7.13	6.56	26.05**	-13.14**
Cross-VII	Nagarkot X SLS-61	-1.05	-8.91**	3.52	-17.02**	-0.71	-0.71	12.97**	1.67	2.12	1.80	21.18**	-2.65
Cross-VIII	Janki X SLS-61	-5.13**	-11.55**	-2.20	-9.48**	-1.19	-1.19	12.43**	-4.57**	3.97	-0.43	17.79**	-18.25**
Cross-IX	Rashmi X SLS-61	-6.30**	-13.90**	-1.76	-4.48*	1.29	0.23	16.49**	0.23	-5.58	-11.81**	20.18**	-24.69**
Cross-X	Mukta X SLS-61	-1.32	-5.49**	-1.32	-4.02*	2.75**	2.14*	16.22**	-1.16	-4.04	-7.86	8.99	2.77
Cross-XI	Chambal X Meera	7.43**	4.55*	11.45**	1.58	-1.08	-1.19	11.89**	1.69	4.72	-6.61	39.47**	-5.50*
Cross-XII	Nagarkot X Meera	9.65**	3.49*	17.62**	3.37*	1.43	1.19	15.14**	4.70**	5.48	-5.22	41.55**	10.75**
Cross-XIII	Janki X Meera	5.83**	1.20	11.89**	-2.36	-1.90*	-2.14*	11.35**	-0.24	11.49**	-3.83	43.62**	13.39**
Cross-XIV	Rashmi X Meera	7.38**	1.16	15.42**	-4.58**	-1.77*	-3.02**	12.70**	-7.43**	-18.05**	-21.63**	17.03**	-17.35**
Cross-XV	Mukta X Meera	2.58	0.84	5.29**	-5.86**	-0.84	-1.19	11.89**	-5.56**	-11.44**	-23.44**	14.33**	-5.33
CD. at 5%		2.59	2.99	2.99	2.99	2.07	2.39	2.39	2.39	4.70	5.43	5.43	5.43
CD. at 1%		3.43	3.96	3.96	3.96	2.75	3.17	3.17	3.17	6.24	7.20	7.20	7.20

*, ** --Significant at 5% and 1% level of significance respectively.MP = mid parent, BP = better parent, ID = inbreeding depression

Table 3: Contd. Estimates of heterosis (MP, BP and Check) and inbreeding depression in per cent for No. of primary branches per plant, No. of capsules per plant and No. of seeds per capsule in linseed

Cross No	Hybrid combinations	No. of primary branches per plant				No. of capsules per plant				No. of seeds per capsule			
		MP	BP	Check	ID	MP	BP	Check	ID	MP	BP	Check	ID
Cross-I	Chambal X BAU-13-1	13.33	-5.56	-19.05	29.41	98.02**	63.93**	88.09**	27.50**	-17.24**	-17.24**	-11.11	-4.16
Cross-II	Nagarkot X BAU-13-1	67.74**	36.84*	23.81	19.23	79.18**	38.24**	91.54**	28.48**	-7.41	-13.79*	-7.41	0.00
Cross-III	Janki X BAU-13-1	-48.39**	-57.89**	-61.90**	-62.50	-12.20	-30.77**	-9.72	-30.56	-11.11*	-17.24**	-11.11	-16.67*
Cross-IV	Rashmi X BAU-13-1	-35.48*	-47.37**	-52.38**	-50.15	-31.37*	-41.25**	-37.93*	-99.50**	-16.98**	-24.14**	-18.52**	-4.55
Cross-V	Mukta X BAU-13-1	23.08	14.29	-23.81	-6.25	88.05**	80.15**	47.96**	17.37	11.54*	0.00	7.41	0.00
Cross-VI	Chambal X SLS-61	9.09	0.00	-14.29	44.44**	56.07**	30.05*	49.22**	33.82**	-3.85	-13.79*	-7.41	-8.00
Cross-VII	Nagarkot X SLS-61	-11.76	-21.05	-28.57*	-40.00*	38.48**	7.47	48.90**	-14.32	8.33	4.00	-3.70	7.69
Cross-VIII	Janki X SLS-61	5.88	-5.26	-14.29	11.11	52.12**	20.67	57.37**	38.05**	0.00	-4.00	-11.11	-12.50
Cross-IX	Rashmi X SLS-61	-35.29**	-42.11**	-47.62**	9.09	-22.20	-32.94*	-29.15	-23.01	10.64	8.33	-3.70	-3.84
Cross-X	Mukta X SLS-61	10.34	6.67	-23.81	-12.50	62.06**	56.49**	28.53	-34.39**	17.39**	17.39*	0.00	14.81*
Cross-XI	Chambal X Meera	27.27	16.67	0.00	52.38**	35.12**	24.04	42.32**	37.89**	0.00	-10.34	-3.70	-7.69
Cross-XII	Nagarkot X Meera	23.53	10.53	0.00	23.81	77.27**	50.00**	107.84**	26.40**	20.83**	16.00*	7.41	24.14**
Cross-XIII	Janki X Meera	23.53	10.53	0.00	4.76	62.33**	40.87**	83.70**	15.87	0.00	-4.00	-11.11	-4.16
Cross-XIV	Rashmi X Meera	-5.88	-15.79	-23.81	6.25	63.92**	56.38**	65.20**	31.50**	-2.13	-4.17	-14.81*	0.00
Cross-XV	Mukta X Meera	51.72**	46.67*	4.76	36.36**	179.93**	159.80**	149.22**	64.03**	8.70	8.70	-7.41	4.00
CD. at 5%		1.72	1.99	1.99	1.99	27.33	31.56	31.56	31.56	0.99	1.14	1.14	1.14
CD. at 1%		2.29	2.64	2.64	2.64	36.26	41.86	41.86	41.86	1.31	1.52	1.52	1.52

*, ** --Significant at 5% and 1% level of significance respectively.MP = mid parent, BP = better parent, ID = inbreeding depression

Table 4: Contd. Estimates of heterosis (MP, BP and Check) and inbreeding depression in per cent for Capsule diameter (mm), Seed yield per plant (g) and 1000-seed weight (g) in linseed

Cross No	Hybrid combinations	Capsule diameter (mm)				Seed yield per plant (g)				1000-seed weight (g)			
		MP	BP	Check	ID	MP	BP	Check	ID	MP	BP	Check	ID
Cross-I	Chambal X BAU-13-1	1.85*	-1.05	15.78**	10.13**	126.63**	90.83**	308.23**	43.29**	21.59**	9.92**	106.77**	20.32**
Cross-II	Nagarkot X BAU-13-1	3.39**	-5.21**	10.91**	8.41**	114.04**	78.66**	290.55**	50.69**	18.41**	2.42**	92.66**	20.30**
Cross-III	Janki X BAU-13-1	4.56**	-4.60**	11.63**	14.55**	14.70	4.20	86.69**	9.15	-14.42**	-23.59**	43.73**	-6.19**
Cross-IV	Rashmi X BAU-13-1	5.60**	0.70	17.83**	17.70**	-27.82	-33.87	16.26	-84.35**	-11.27**	-21.28**	48.08**	-12.80**
Cross-V	Mukta X BAU-13-1	1.04	0.00	17.01**	8.58**	149.50**	140.05**	280.08**	34.55**	20.35**	10.41**	107.69**	1.72**
Cross-VI	Chambal X SLS-61	-3.36**	-5.34**	4.46**	2.80**	58.20**	27.65	173.07**	39.97**	9.18**	7.83**	63.89**	21.21**
Cross-VII	Nagarkot X SLS-61	-0.86	-4.74**	0.82	5.39**	77.05**	41.70**	209.76**	22.28*	39.89**	34.74**	99.72**	29.14**
Cross-VIII	Janki X SLS-61	5.72**	1.06	6.97**	3.45**	99.54**	72.89**	209.76**	45.80**	27.33**	27.15**	88.46**	13.91**
Cross-IX	Rashmi X SLS-61	8.89**	8.74**	15.42**	16.20**	-22.57	-32.37	18.90	-23.25	-2.81**	-3.65**	42.81**	-11.32**
Cross-X	Mukta X SLS-61	0.44	-3.40**	10.71**	0.51	79.86**	64.51**	160.47**	-39.33**	12.41**	9.25**	71.58**	-6.27**
Cross-XI	Chambal X Meera	-3.92**	-5.06**	4.76**	0.39	54.34**	30.40*	178.96**	49.51**	28.69**	26.76**	92.66**	16.08**
Cross-XII	Nagarkot X Meera	-1.07	-5.75**	1.54	3.68**	94.62**	62.99**	256.30**	46.32**	22.46**	18.26**	74.36**	11.64**
Cross-XIII	Janki X Meera	1.88*	-3.42**	4.05**	6.55**	93.90**	76.80**	216.77**	38.08**	8.56**	8.43**	60.26**	9.29**
Cross-XIV	Rashmi X Meera	0.07	-0.67	7.02**	3.02**	83.97**	69.19**	197.46**	40.42**	4.45**	3.82**	53.06**	0.93
Cross-XV	Mukta X Meera	-1.52	-4.47**	9.48**	0.84	176.28**	166.88**	322.56**	63.42**	41.57**	37.23**	115.53**	14.97**
CD. at 5%		0.11	0.13	0.13	0.13	1.78	2.05	2.05	2.05	0.07	0.08	0.08	0.08
CD. at 1%		0.15	0.17	0.17	0.17	2.36	2.72	2.72	2.72	0.09	0.11	0.11	0.11

*, ** --Significant at 5% and 1% level of significance respectively.MP = mid parent, BP = better parent, ID = inbreeding depression

Table 5: Contd. Estimates of heterosis (MP, BP and Check) and inbreeding depression in per cent for Oil content (%) in linseed

Cross No	Hybrid combinations	Oil content (%)			
		MP	BP	Check	ID
Cross-I	Chambal X BAU-13-1	16.43**	-1.39	42.34**	16.90**
Cross-II	Nagarkot X BAU-13-1	14.86**	0.79	45.49**	21.90**
Cross-III	Janki X BAU-13-1	-5.83**	-20.63**	14.58**	13.71**
Cross-IV	Rashmi X BAU-13-1	-9.80**	-19.60**	16.06**	-6.21*
Cross-V	Mukta X BAU-13-1	11.55**	-8.23**	32.47**	2.86
Cross-VI	Chambal X SLS-61	2.93	1.37	1.53	-21.55**
Cross-VII	Nagarkot X SLS-61	0.70	-4.78	3.78	-5.08
Cross-VIII	Janki X SLS-61	49.81**	48.41**	46.89**	19.35**
Cross-IX	Rashmi X SLS-61	25.04**	16.26**	31.36**	7.84**
Cross-X	Mukta X SLS-61	14.42**	12.09**	8.87**	-15.27**
Cross-XI	Chambal X Meera	20.88**	16.68**	25.60**	5.04*
Cross-XII	Nagarkot X Meera	30.03**	29.23**	40.84**	2.37
Cross-XIII	Janki X Meera	17.64**	12.90**	21.53**	22.46**
Cross-XIV	Rashmi X Meera	10.38**	7.77**	21.76**	11.64**
Cross-XV	Mukta X Meera	53.14**	42.85**	53.77**	14.41**
CD. at 5%		1.44	1.66	1.66	1.66
CD. at 1%		1.91	2.21	2.21	2.21

*, ** --Significant at 5% and 1% level of significance respectively.MP = mid parent, BP = better parent, ID = inbreeding depression

Heterosis breeding has come to play a pivotal role in crop improvement programme for obtaining higher yield production. Heterosis is a complex genetic phenomena depending upon the balance of additive, dominance and interaction components as well as the distribution of the genes in the parental lines. The presence or absence of heterosis is not itself an indication of the presence or absence of any particular type of gene action or interactions. Heterosis response has been expressed as a deviation of F_1 mean from values of either mid parent or better parent or standard check variety. It may however be kept in mind that while selecting best cross combination besides heterotic response, the *per se* performance of the crosses should also be given due consideration. In present investigation heterosis in fifteen F_1 crosses over mid parent, better parent and over economic check (T-397) and inbreeding depression in F_2 for ten characters were studied.

The value of heterosis revealed that none of the cross exhibited significant heterosis for all the characters over mid parent, better parent and check variety. The degree and direction of heterotic response varied not only from character to character but also from cross to cross. In general, considerable amount of significant desirable heterosis over mid parent observed for most of the characters. Significant and desirable heterosis over mid parent was observed in four crosses (Cross-IV, V, VIII and IX) for days to 50% flowering, two crosses (Cross-XIII and XIV) for days to maturity, three crosses (Cross-IV, XIV and XV) for plant height, two crosses (Cross-II and XV) for number of primary branches per plant, twelve crosses (Cross-I, II, V, VI, VII, VIII, X, XI, XII, XIII, XIV and XV)) for number of capsules per plant, three crosses (Cross-V, X and XII) for number of seeds per capsule, seven crosses (Cross-I, II, III, IV, VIII, IX and XIII) for capsule diameter, twelve crosses for each seed yield per plant and 1000-seed weight (Cross-I, II, V, VI, VII, VIII, X, XI, XII, XIII, XIV and XV) and eleven crosses (Cross-I, II, V, VIII, IX, X, XI, XII, XIII, XIV and XV) for oil content.

Heterosis over better parent (heterobeltiosis) was observed significant and in desirable direction for seven crosses (Cross-II, IV, V, VII, VIII, IX and X) for days to 50% flowering, five crosses (Cross-I, II, IV, XIII and XIV) for days to maturity, four crosses (Cross-IV, IX, XIV and XV) for plant height, two crosses (Cross-II and XV) for number of primary branches per plant, nine crosses (Cross-I, II, V, VI, X, XII, XIII, XIV and XV) for number of capsules per plant, two crosses (Cross- X and XII) for number of seeds per capsule, one cross that is Cross-IX for capsule diameter, eleven crosses (Cross-I, II, V, VII, VIII, X, XI, XII, XIII, XIV and XV) for seed yield per plant, twelve crosses (Cross-I, II, V, VI, VII, VIII, X, XI, XII, XIII, XIV and XV) for 1000-seed weight and eight crosses (Cross-VIII, IX, X, XI, XII, XIII, XIV and XV) for oil content.

Similarly, heterosis over check variety T-397 was found significant and desirable in eleven crosses (Cross-I, II, V, VI, VII, VIII, XI, XII, XIII XIV and XV) for number of capsules per plant, thirteen crosses for each capsule diameter (Cross-I, II, III, IV, V, VI, VIII, IX, X, XI, XIII, XIV and XV) seed yield per plant (Cross-I, II, III, V, VI, VII, VIII, X, XI, XII, XIII, XIV and XV) and oil content (Cross-I, II, III, IV, V, VIII, IX, X, XI, XII, XIII, XIV and XV). No significant desirable heterosis over check was seen for days to 50% flowering, days to maturity, plant height, number of primary branches per plant and number of seeds per capsule for any of the crosses while for 1000-seed weight all the fifteen crosses exhibited significant positive heterosis.

The result of Singh *et al.* (1983) [23] for number of capsules per plant, 1000-seed weight and capsule size, Rao and Singh (1983) [16] and Verma and Mahto (1996) [31] for days to maturity, seed yield per plant, number of capsules per plant, number of primary branches per plant, plant height and number of seeds per capsule, Mahto and Rahman (2001) [13] for earliness, number of capsules per plant, 1000-seed weight and for number of capsules per plant, Kusalkar *et al.* (2002) [12] for number of capsules per plant, number of seeds per capsule, oil content, 1000-seed weight and seed yield per plant, Sharma *et al.* (2005) [21] for seed yield per plant, oil content, days to 50% flowering, number of primary branches per plant, days to maturity and 1000-seed weight, Rao (2006) [17] for number of capsules per plant and number of seeds per plant, Kiran *et al.* (2012) [8] for days to 50% flowering, seed yield per plant and plant height, Kumar *et al.* (2013) [9] for number of primary branches per plant, number of capsules per plant, 1000-seed weight, seed yield per plant, plant height and number of seeds per capsule, Pali and Mehta (2014) [15] for seed yield per plant, days to 50% flowering, number of capsules per plant, and oil content, Reddy *et al.* (2013) [18] for plant height, days to 50% flowering, number of capsules per plant, 1000-seed weight and seed yield per plant and Sharma *et al.* (2018) [20] for both days to 50% flowering, days to maturity, plant height, number of primary branches per plant, number of capsules per plant, number of seeds per capsule and seed yield per plant and Kumar *et al.* (2019) [11] for most of the characters were in conformity of the present finding. While considering the significant and useful heterosis over mid parent, better parent and economic parent, the best crosses were cross-I (Chambal x BAU-13-1), II Nagarkot x BAU-13-1), V (Mukta x BAU-13-1), VII (Nagarkot x SLS-61), VIII (Janki x SLS-61), x (Mukta x SLS-61), XI (Chambal x Meera), XII (Nagarkot x Meera), XIII (Janki x Meera), XIV (Rashmi x Meera) and XV (Mukta x Meera) for seed yield per plant. It was also found that increase in seed yield in these crosses were mostly due to desirable heterotic response of important component traits like number of primary branches per plant in two crosses and number of seeds per capsule in three crosses. Heterotic responses were not observed uniformly in all eleven crosses, however, number of capsules per plant, capsule diameter and 1000-seed weight invariably had shown heterotic response with most of the eleven crosses. Singh *et al.* (1987) [22], Kusalkar *et al.* (2002) [12], Kiran *et al.* (2012) [8], Reddy *et al.* (2013) [18], Singh *et al.* (2014) [24], Sharma *et al.* (2018) [20] and Kumar *et al.* (2021) [10] also reported the contribution of these components to the heterosis for seed yield per plant.

Inbreeding depression in F_2 generation was estimated for all the characters under study. The result indicted that only one cross i.e., Cross-VII for days to 50% flowering, three crosses (Cross-II, VI and VII) for days to maturity, two crosses (Cross-VIII and VIII) for plant height, three crosses (Cross-VI, XI and XV) for number of primary branches per plant, eight crosses (Cross-I, II, VI, VIII, XI, XII, XIV and XV) for number of capsules per plant, two crosses (Cross-X and XII) for number of seeds per capsule, twelve crosses (Cross-I, II, III, IV, V, VI, VII, VIII, IX, XII, XIII and XIV) for capsule diameter, eleven crosses (Cross-I, II, V, VI, VII, VIII, XI, XII, XIII, XIV and XV) for seed yield per plant, ten crosses (Cross-I, II, V, VI, VII, VIII, XI, XII, XIII and XV) for 1000-seed weight and nine crosses (Cross-I, II, III, VIII, IX, XI, XIII, XIV and XV) for oil content revealed significant positive inbreeding depression indicating detoriation in their performance in next generation. It might be due to lack of segregation of desirable genes responsible for dominance effect or may be due to tight linkage of desirable genes or due to phenomenon of fixing of heterozygocity. Such crosses could prove useful in diallel selective mating system (Tonde *et al.*, 2016) [28]. Srivastava *et al.* (2003) [25] and Swarnkar *et al.* (2003) [26] for seed yield per plant, Sharma *et al.* (2005) [21] for days to 50% flowering, number of primary branches per plant, days to maturity and 1000-seed weight, Sharma *et al.* (2018) [20] days to 50% flowering, days to maturity, plant height, number of primary branches per plant, number of capsules per plant, number of seeds per capsule and seed yield per plant, Kiran and Kanojia (2014) [7] for days to 50% flowering, plant height, number of primary branches per plant, number of capsules per plant and 1000-seed weight also reported the inbreeding depression.

Thus, the crosses showing significant economic heterosis in some crosses associated with high degree of inbreeding depression, in such hybrids significant heterosis in F_1 and high degree of inbreeding depression in F_2 could be attributed to high magnitude of non-additive gene effects. In contrast, the other heterotic crosses having high economic heterosis showed negative inbreeding depression, indicating the presence of additive gene effects. These crosses may be utilized following pedigree method for the selection of desirable segregants in advanced generation.

Acknowledgement

We are thankful to the Department of Genetics and Plant Breeding, Birsa Agricultural University, Kanke, Ranchi for providing all necessary facilities and support during the course of investigation.

References

1. Anonymous. Linseed Annual Report, ICAR-IIOR 2019-20.
2. Anonymous. Linseed Annual Report, ICAR-IIOR 2020-21.
3. Bhatty RS, Rowland GG. Measurement of alphalinolenic acid in the development of edible oil flax. J. Am. Oil Chem. Soc 1990;67:364-367.
4. Chopra P, Badiyala D. Influence of sowing time on performance of linseed (*Linum usitatissimum* L.) varieties under mid hill conditions of Himachal Pradesh. Journal of Oilseeds Research 2016;33(4):256-258.
5. Dillman AC. Natural crossing in flax. J Am. Soc. Agron 1938;30:279-286.
6. Fonseca S, Patterson F. Hybrid vigour in seven parent diallel crosses in common winter wheat (*Triticum aestivum* L.). Crop Sciences 1968;8:85-95.
7. Kiran Kanojia RK. Heterosis and inbreeding depression in linseed (*Linum usitatissimum* L.). New Agriculturist 2014;25(2):185-188.
8. Kiran Sood VK, Bhateria S. Detection of genetic components of variation for yield, fibre and quality traits in flax (*Linum usitatissimum* L.). J Agric. Sci 2012;4(10):224-231.
9. Kumar S, Kumar R, Singh MP, Kumar S, Singh S, Kumar S *et al.* Effect of heterosis and inbreeding depression in linseed (*Linum usitatissimum* L.). Progressive Research 2013;8;438-441.
10. Kumar S, Ram S, Ahmad E, Chakraborty M, Verma N, Lal HC *et al.* Estimation of Heterosis and Inbreeding Depression in Linseed (*Linum usitatissimum* L.) for Yield, its Attributing Traits and Oil Content. Int. J Curr. Microbiol. App. Sci 2021;10(02):1185-1191.
11. Kumar S, Ram S, Chakraborty M, Ahmad E, Verma N, Lal HC *et al.* Studies of heterosis and inbreeding depression in linseed (*Linum usitatissimum* L.). Int. J. Chemical Studies 2019;SP6:972-976.
12. Kusalkar AM, Patil BR, Thawari SB, Khatod JP. Heterosis studies in linseed (*Linum usitatissimum* L.). J. Soils and Crops 2002;12(2):196-198.
13. Mahto C, Rahman MH. Heterosis for yield and yield components in linseed *(Linum usitatissimum* L.). J Res., Birsa Agricultural University 2001;13(2):189-191.
14. Meredith WR, Bridge RR. Heterosis and geneaction in cotton, (*Gossypium hirsutum*). Crop Sciences 1972;12:304-310.
15. Pali V, Mehta N. Combining ability and heterosis for seed yield and it's attributes in linseed (*Linum itatissimum* L.) The Bioscan 2014;9(2):701-706.
16. Rao SK, Singh SP. Heterosis and inbreeding depression in linseed. Indian J agric. Sci 1983;53(6):409-417.
17. Rao SS. Heterosis and inbreeding depression in linseed (*Linum usitatissimum* L.). J Oilseeds Res 2006;23(2):187-190.
18. Reddy MP, Arsul BT, Shaik NR, Maheshwari JJ. Estimation of heterosis for some trait in linseed (*Linum usitatissimum* L.). J Agri and Vet. Sci 2013;2(5):11-17.
19. Richharia RH. Linseed. The Indian Central Oiseeds Committee 1962. Hyderabad, India.
20. Sharma A, Srivastava A, Chauhan MP. Heterosis and Inbreeding Depression in Linseed (*Linum usitatissimum* L.). Int. J Curr. Microbiol. App. Sci 2018;**7**(2):554-559.
21. Sharma R, Tiwari SK, Singh P, Ramakant. Heterobeltiosis and inbreeding depression in linseed. Agriculture Science Digest 2005;25(1):35-37.
22. Singh P, Srivastava AN, Singh IB, Mishra R. Heterosis and inbreeding depression in relation to *per se* performance in linseed. Farm Sci. J 1987;2(1):68-73.
23. Singh RS, Singh S, Chaudhary RK. Heterobeltiosis in relation to *per se* performance and effect of general combining ability in linseed. Pre-congress Scientific meeting on Genetics and improvement of heterotic system 1983, 14.
24. Singh VK, Verma PN, Sharma V, Verma IK, Paswan SK, Chauhan MP. Estimation of heterosis for yield and its contributing attributes in linseed (*Linum usitatissimum* L.) The Ecoscan (Special issue) 2014;6:81-84.
25. Srivastava RL, Swarnkar SK, Kerkhi SA, Dubey SD, Malik YP. Heterosis and inbreeding depression in linseed under salt affected soil. ISOR National Seminor: stress management in oilseeds. Rajendranagar, Hyderabad 2003.
26. Swarnkar SK, Singh P, Srivastava RL, Singh P. Combining ability analysis in linseed (*Linum usitatissimum* L.). Progressive Agriculture 2003;1(2):103-106.
27. Tadesse T, Singh H, Weyessa B. Correlation and path coefficient analysis among seed yield traits and oil content in Ethiopian linseed germplasm. International Journal of Sustainable Crop Production 2009;4:8-16.
28. Tonde NG, Kale VS, Nagre PK, Lajurkar VG. Heterosis and inbreeding depression studies in okra *Abelmoschus esculentus* (L.) Moench. The Bioscan 2016;11(3):1979-

1984.
29. Toure A, Xueming X. Flax seed lignans: source, biosynthesis, metabolism, antioxidant activity, bio-active components, and health benefits. Comprehensive Reviews in Food and Science and Food Safety 2010;9(3):261-269.
30. Turner JM. A study of heterosis in upland cotton II Combining ability and inbreeding effects. Agron. J 1953;43:487-490.
31. Verma AK, Mahto JL. Hybrid vigour in linseed (*Linum usitatissimum* L.) for yield and yield attributes under rain-fed and irrigated environments. J Trop. Agric 1996;34(1):54-57.