The Bioscan 9(2): 701-706, 2014 (Supplement on Genetics and Plant Breeding)
AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES
www.thebioscan.in

COMBINING ABILITY AND HETEROSIS FOR SEED YIELD AND IT'S ATTRIBUTES IN LINSEED (*LINUM USITATISSIMUM* L.)

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KEYWORDS
Combining ability
Heterosis
Line × Tester
Linseed

Received on :
11.12.2013

Accepted on :
26.03.2014

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ABSTRACT
Fourteen parents were crossed in line × tester fashion comprising 10 lines and 4 testers to estimate combining ability and heterosis in linseed for seed yield and its components. The analysis for combining ability revealed significant mean sum of squares of both general combining ability (GCA) and specific combining ability (SCA) for all the characters which indicated the presence of both additive and non-additive gene actions. RLC-132 and R-4129 was good general combiner for most of the characters including seed yield. The tester RLC-92 and Deepika was also a good general combiner for days to 50% flowering, days to maturity, plant height, 1000 seed weight, harvest index and seed yield plant^{-1}. Crosses RLC-132 × RLC-92, R-4154 × Indira Alsi-32, R-4158 × Deepika, R-4129 × Kartika and RLC-132 × Kartika was a good specific combiner for seed yield per plant and for other yield component. The hybrid R-4154 × Indira Alsi-32 with good specific combining ability for days to maturity can be used for yield improvement in linseed. In general for yield and other yield attributing traits the promising hybrids with high heterosis were RLC-132 × RLC-92 for days to 50% flowering, 1000 seed weight and seed yield plant^{-1}, R-2678 × Indira Alsi-32 for number of capsules plant^{-1} and R-2678 × Kartika for oil content. These crosses combinations could be utilized for further use in breeding programme for improvement in yield of linseed.

INTRODUCTION

Linseed (*Linum usitatissimum* L.) belongs to the genus *Linum* of the family Linaceae commonly known as *"Alsi"* and has 2n = 30 chromosomes. Linseed is one of the important *rabi* oilseed crops of India, cultivated in light soil under one or two irrigation in Madhya Pradesh, Chhattisgarh, Uttar Pradesh, Maharashtra, Rajasthan, West Bengal, Karnataka, Orissa and Bihar. In Chhattisgarh, linseed is grown mostly rainfed as "*utera*" as well as in crop fields whereas in overseas countries it is widely grown in cool temperate regions of Argentina, Northern Europe, China, Russia, USA and Canada (Gauraha *et al.,* 2011). It is cultivated for the main products fibre (flax fibre) and seed oil (linseed) or both (dual purpose linseed), but recently it has gained a new interest in the emerging market of functional food due to its high content of fatty acids, alpha linolenic acid (ALA), an essential Omega-3 fatty acid and lignin oligomers which constitute about 57 % of total fatty acids in linseed (Reddy *et al.,* 2013).

Combining ability is a powerful tool to select good combiners and thus selecting the appropriate parental lines for hybridization programme. In addition, the information on nature of gene action will be helpful to develop efficient crop improvement programme. General combining ability is due to additive and additive × additive gene action and is fixable in nature while specific combining ability is due to non-additive gene action which may be due to dominance or epistasis or both and is non-fixable. The presence of non-additive genetic variance is the primary justification for initiating the hybrid breeding programme (Cockerham, 1961). Heterosis breeding is an important crop improvement method adopted in many crops all over the world. It is a quick and convenient way of combining desirable characters which has assumed greater significance in the production of F_1 hybrids (Ramesh *et al.,* 2013 and Jhajharia *et al.,* 2013). Several workers like Singh *et al.* (1987), Thakur *et al.* (1987), Khorgade *et al.* (1990) and Khorgade *et al.* (1993) have reported combining ability on seed yield and its attributing traits in linseed.

Commercial exploitation of heterosis in linseed is regarded as a breakthrough in the field of linseed improvement for developing hybrids. Development of better hybrids using stable high yielding lines shall raise the yield of this crop. In order to achieve high yielding cross combination, it is essential to evaluate available promising diverse lines and their hybrid combinations for yield and yield components (Singh *et al.,* 2006). The aim of heterosis analysis is to find out the best combination of crosses giving high degree of heterobeltiosis and characterization of hybrids for commercial exploitation. The studies of heterosis in linseed have also been reported by Saraswat *et al.* (1993), Foster *et al.* (1998), Rede (1999), Ratnaparkhi *et al.* (2005), Sharma *et al.* (2005) and Reddy *et al.* (2013).

There are several techniques for the evaluation of varieties or strains in terms of their combining ability especially line × tester analysis is one of them. This technique was developed by Kempthorne in 1957. Keeping in view with the above problem, the present investigation is taken up with the

Table 1: Analysis of variance of combining ability for different characters in linseed

Source	D.F.	Mean Sum of Square										
		Days to 50% flowering	Days to maturity	Plant height (cm)	Number of branches plant^{-1}	Number of capsules plant^{-1}	Number of seeds capsule^{-1}	1000 seed weight	Oil content (%)	Biological yield plant^{-1}	Harvest index (%)	Seed yield plant^{-1}
Genotypes	53	19.064**	17.034**	22.620**	0.796**	157.257**	1.040**	0.004**	6.654**	1.878**	11.879**	0.450**
Parents	13	22.345**	21.465**	9.999*	0.287	85.112**	0.350**	0.002**	2.677**	0.733	2.413**	0.134
Crosses	39	16.862**	15.297**	23.422**	1.064**	180.207**	1.347**	0.005**	8.508**	2.472**	15.720**	0.597**
Parents vsCrosses	1	35.784**	11.875*	120.171**	0.012	347.570**	1.103**	0.0009	5.371**	0.315	20.246**	0.362*
Error	106	3.167	2.455	3.851	0.209	21.289	0.051	0.0004	0.268	0.896	0.267	0.075
Lines	9	33.458**	25.548**	40.960**	2.817**	569.106**	4.196**	0.013**	23.692**	6.309**	43.160**	1.748**
Testers	3	65.783**	54.169**	87.982**	0.088	10.776	0.057	0.011	4.123**	2.786	10.464**	0.533**
Lines x Testers	27	3.943	3.693	3.893	0.350	13.996	0.138*	0.0011**	1.646	0.500	2.875**	0.032
Error	78	3.212	2.527	3.610	0.241	16.312	0.052	0.0004	0.256	0.896	0.300	0.075

*, ** Significant at 5% and 1% level, respectively

Table 2: General combining ability effect of parents for different characters in linseed

Lines	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of branches plant^{1}	Number of capsules plant^{1}	Number of seeds capsule^{-1}	1000 seed weight	Oil content (%)	Biological yield plant^{1}	Harvest index (%)	Seed yield plant^{1}
RLC-122	0.65	0.70	-0.32	-0.42	-7.83**	-0.10	0.02*	0.25	0.19	-1.28**	-0.13
RLC-132	1.24*	-2.30	-1.50	0.71**	8.01**	0.66**	0.04**	1.74**	0.87	2.50**	0.51**
R-2678	0.77	0.81	3.59**	-0.62	-5.72**	-0.45**	-0.01	-1.58**	-0.19	-1.41**	-0.20
R-4129	1.72**	-0.97	-1.77	0.51*	11.03**	0.79**	0.03*	1.82**	0.93*	2.54**	0.53**
R-4140	1.10*	0.92	1.90*	-0.42	-3.99	-0.30**	-0.03*	-1.06**	-0.75	-1.29**	-0.53**
R-4141	-0.35	2.48**	0.39	-0.29	-7.17**	-1.10**	-0.07**	-2.18**	-1.36**	-2.79**	-0.63**
R-4152	0.53	-1.63	-2.28*	0.53*	5.67**	0.48**	0.03*	1.01**	0.30	1.73**	0.25
R-4154	1.59**	0.87	-1.32	0.39	2.34	0.87**	0.02*	1.93**	0.83	3.14**	-0.34
R-4158	0.43	2.34**	-1.64	-0.40	-6.14**	-0.49**	0.03*	0.67	0.75	2.12**	-0.16
R-4168	-0.24	0.94	4.19**	0.32	-3.54	-0.34**	-0.01	-1.64**	-0.39	-1.11**	-0.25
SE (gi) ±	0.412	0.611	0.687	0.233	1.87	0.094	0.0081	0.189	0.409	0.254	0.141
Testers											
Kartika	-0.60	-0.73	-0.22	0.07	-0.08	0.05	0.02*	0.35*	0.14	0.29	0.10
Deepika	1.80**	-1.11*	-1.93**	-0.02	0.75	-0.05	0.03*	0.33*	0.27	0.52**	0.46**
Indira Alsi-32	0.86	1.84**	2.15**	-0.05	-0.67	0.12	-0.02*	-0.50**	-0.41	-0.80**	-0.18*
RLC 92	1.56**	1.91**	2.32**	-0.07	0.91	0.21	0.05**	0.16	0.44	0.62**	0.57**
SE (gi) ±	0.232	0.354	0.429	0.117	0.894	0.051	0.0050	0.121	0.223	0.222	0.08

*, ** Significant at 5% and 1% level, respectively

following objectives: To study the general and specific combining ability of parents and crosses for seed yield and yield contributing characters and heterosis for seed yield and different yield characters.

MATERIALS AND METHODS

The experimental material comprised of ten promising lines *viz.*, RLC-122, RLC-132, R-2678, R-4129, R-4140, R-4141, R-4152, R-4154, R-4158 and R-4168 of linseed (having higher yield and better agronomic characters), which were crossed with four different testers *viz.*, Kartika, Deepika, Indira Alsi-32 and RLC-92 (having broad genetic base and wider adaptability) in Line × Tester fashion to generate 40 F_1s. The seeds of 54 entries (14 parents and 40 F_1s hybrids) were sown in the field using a Randomized Complete Block Design with three replications during *Rabi*, 2012-13. This experiment was carried out at Research cum Instructional Farm, Department of Genetics and Plant Breeding, College of Agriculture, AICRP on Linseed, I.G.K.V., Raipur, Chhattisgarh. The entries were sown in a single row of 3 meter length with inter and intra-row spacing of 30 cm and 10 cm, respectively. All the cultural practices and plant protection measures were undertaken as per the recommendations to raise pest free crop. Observations were recorded on five randomly selected plants for eleven characters *viz.*, days to 50% flowering, days to maturity, plant height, number of branches plant^{-1}, number of capsules plant^{-1}, number of seeds capsule^{-1}, 1000 seed weight, oil content, biological yield plant^{-1}, harvest index and seed yield plant^{-1}. The data recorded on the material generated as per Line × Tester model of Kempthorne (1957) were subjected to analysis of variance as per the Line × Tester model given by Singh and Chaudhary (1977).

RESULTS AND DISCUSSION

The analysis of variance for combining ability revealed highly significant differences of the line × tester component for all the characters, indicating that the material chosen was desirable. The lines showed significant differences for all the characters under study while the testers exhibited significant differences for days to 50% flowering, days to maturity, plant height, oil content, harvest index and seed yield plant^{-1}. The variance due to parents *vs* crosses was also significant for all the characters (except for number of branches plant^{-1}, 1000 seed weight and biological yield plant^{-1}) indicating presence of heterosis for these characters (Table 1). Similar results were also reported by Singh *et al.* 1987, Thakur *et al.* 1987 and

Table 3: Specific combining ability effect of hybrids for different characters in linseed

Crosses (Hybrids)	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of branches plant^{-1}	Number of capsules plant^{-1}	Number of seeds capsule^{-1}	1000 seed weight	Oil content (%)	Biological yield plant^{-1}	Harvest index (%)	Seed yield plant^{-1}
RLC-122 × Kartika	0.89	1.73*	0.24	0.26	-2.14**	-0.30*	-0.01	0.46	-0.53	-0.42	-0.14
RLC-122 × Deepika	0.75	0.11	-0.31	0.02	1.96**	0.14	0.03*	0.57*	0.87	0.22	0.18*
RLC-122 × Indira Alsi-32	-0.33	-1.84*	0.08	-0.28	0.18	0.15	-0.02	1.03**	-0.34	0.22	0.02
RLC-122 × RLC-92	0.70	0.74	0.86	0.37	0.76	0.20	0.01	0.33	0.81	0.39	0.11
RLC-132 × Kartika	-1.21*	-0.27	0.62	0.13	0.75	0.15	0.02	-0.78**	-0.11	1.54**	0.26**
RLC-132 × Deepika	0.65	-0.56	-0.67	0.02	-0.42	0.05	-0.01	-0.78**	-0.11	-1.18**	0.12
RLC-132 × Indira Alsi-32	0.001	0.83	0.05	-0.15	-0.33	-0.20	0.01	-0.25	0.18	-0.36	-0.01
RLC-132 × RLC-92	1.78**	1.33*	1.22**	1.29**	1.44**	-0.66**	0.02	0.47	0.39	-0.97**	0.38**
R-2678 × Kartika	0.37	0.62	1.46**	-0.34	-1.85**	-0.21	0.02	-1.04**	0.24	-0.92**	-0.04
R-2678 × Deepika	0.65	0.67	-1.63	0.18	-1.22	0.03	-0.01	-0.23	-0.05	-0.34	-0.02
R-2678 × Indira Alsi-32	0.07	-1.29	0.17	0.52	3.07**	0.17	-0.01	1.27**	-0.19	1.26**	0.06
R-2678 × RLC-92	0.37	0.84	0.68	0.31	0.67	0.19	0.02	0.39	0.67	0.43	0.09
R-4129 × Kartika	1.89**	-0.60	1.32**	0.13	1.26**	0.15	0.01	-0.08	0.36	0.04	0.29**
R-4129 × Deepika	0.57	0.11	2.00	0.09	-0.99	0.12	-0.01	0.20	-0.51	0.34	0.09
R-4129 × Indira Alsi-32	0.42	0.49	-0.68	-0.22	-0.29	-0.27*	0.01	-0.13	0.15	-0.38	-0.02
R-4129 × RLC-92	0.14	0.86	-0.75	0.41	0.91	0.23	0.01	-0.25	0.54	-0.41	0.08
R-4140 × Kartika	-0.16	-1.16	0.48	-0.61*	2.88**	-0.10	0.01	0.07	0.05	0.76*	0.06
R-4140 × Deepika	0.74	0.89	-0.87	0.36	-0.69	-0.12	-0.02	0.25	-0.22	0.22	-0.03
R-4140 × Indira Alsi-32	0.53	0.27	0.39	0.25	-2.20**	0.22	0.01	-0.32	0.17	-0.98**	-0.03
R-4140 × RLC-92	0.61	0.79	0.83	0.34	0.83	0.21	0.02	0.32	0.74	0.53	-0.04
R-4141 × Kartika	0.39	-0.05	-0.87	0.26	-1.00	0.24	-0.03*	-0.18	0.09	-1.13**	-0.09
R-4141 × Deepika	0.45	-0.67	1.04*	-0.24	-0.91	-0.19	0.02	-0.13	0.16	0.22	0.07
R-4141 × Indira Alsi-32	0.19	0.71	-0.17	-0.02	1.91	-0.05	0.01	0.30	-0.25	0.91**	0.02
R-4141 × RLC-92	0.77	0.80	0.77	0.38	0.73	0.14	-0.01	0.34	-0.45	0.48	0.08
R-4152 × Kartika	0.89	-0.27	-0.61	0.17	0.10	0.06	0.01	-0.27	-0.14	0.13	-0.04
R-4152 × Deepika	1.18*	-0.56	0.44	-0.07	2.26**	-0.03	0.01	0.12	-0.15	0.55	0.04
R-4152 × Indira Alsi-32	0.54	0.83	0.17	-0.10	-2.35**	-0.03	0.00	0.15	0.29	-0.68*	0.01
R-4152 × RLC-92	0.04	0.92	0.73	0.29	0.65	0.16	0.02	-0.27	0.55	0.59	0.09
R-4154 × Kartika	0.43	-0.32	0.68	0.17	0.70	0.17	0.02	-0.88**	-0.15	1.34**	0.12
R-4154 × Deepika	0.73	0.73	0.79	0.38	0.71	0.21	0.01	0.43	-0.13	0.45	0.06
R-4154 × Indira Alsi-32	-1.11*	-1.93*	-1.42**	0.40	1.51**	0.24	0.11**	0.49	0.37	0.80*	0.35**
R-4154 × RLC-92	0.35	0.75	-0.85	0.61	0.76	0.21	0.01	-0.35	0.59	-0.33	0.08
R-4158 × Kartika	-2.13**	0.72	0.84	0.43	0.64	0.20	0.02	0.49	0.35	0.29	0.09
R-4158 × Deepika	0.89	1.10*	1.71**	0.26	1.65**	-0.53	0.02	1.23**	0.25	-0.44	0.33**
R-4158 × Indira Alsi-32	0.53	0.76	0.08	-0.25	-0.27	-0.25	0.01	-0.19	0.22	-0.30	0.04
R-4158 × RLC-92	0.74	0.84	0.79	0.35	0.58	0.26	0.02	-0.21	0.63	0.52	0.08
R-4168 × Kartika	-0.32	-0.96	0.68	-0.41	2.18**	-0.20	0.01	0.27	0.25	0.56	0.07
R-4168 × Deepika	0.72	0.54	0.77	0.22	0.52	0.09	-0.01	-0.88**	0.21	0.28	0.11
R-4168 × Indira Alsi-32	0.23	0.69	-0.48	-0.33	0.38	-0.20	0.01	-0.13	0.23	-0.26	-0.02
R-4168 × RLC-92	0.24	0.87	0.65	0.32	0.69	0.16	0.01	0.37	0.71	0.49	0.10
SE(sij)	0.783	0.834	0.886	0.225	2.123	0.120	0.009	0.301	0.489	0.368	0.14

Khorgade *et al.* 1990.

RLC-132 and R-4129 were best general combiners among lines as evident from significant GCA effects for eight characters and R-4140 and R-4152 for seven characters. Among testers Deepika and RLC-92 was found to be the best general combiner for six characters *viz*. Days to 50% flowering, days to maturity, plant height, 1000 seed weight, harvest index and seed yield plant^{-1}. Result indicated that R-4154 and RLC-132 among lines and Deepika, RLC-92 among testers are best combiners for seed yield plant^{-1} (Table 2). Highly significant values for both combining capabilities and greater GCA value received Mishra *et al.* (2013).

Parents showing maximum *per se* performance were also the best general combiner for the characters *viz*. RLC-132 and R-4129 for number of capsules plant^{-1} and oil content. R-4154 for number of seeds cpasule^{-1}, oil content and seed yield plant^{-1}. The *sca* effect of fourty crosses is presented in Table 3. The crosses RLC-132 × RLC-92, R-4154 × Indira Alsi-32, R-4158 × Deepika, R-4129 × Kartika and RLC-132 × Kartika was the best crosses among all crosses for seed yield plant^{-1} and also for other yield component traits like days to 50% flowering, plant height, harvest index and number of capsules plant^{-1}. All these five crosses having significant *sca* effects, recorded higher *per se* performance. As it showed highest *sca* effects for seed yield per plant and harvest index, which are important traits in deciding the potential yield of a genotype. The cross R-4154 × Indira Alsi-32 was the best cross for days to maturity, plant height and 1000 seed weight, R-4158 × Deepika for plant height and oil content, R-4129 × Kartika for days to 50% flowering and plant height while the cross RLC-132 × Kartika also recorded significant *sca* effect for harvest index. Similar results of significant *sca* effects for yield contributing characters were also reported by Jain and Rao (2004), Srivastava *et al.* (2004), Ratnaparkhi *et al.* (2005), Bhateria *et al.* (2006), Rao

Table 4: Promising hybrid combinations with significant specific combining ability effects in linseed

Name of the characters	Promising hybrids (F_1s)
Days to 50% flowering	R-4152 × Kartika, RLC-132 × RLC-92, R-4129 × Kartika,
Days to maturity	R-4154 × Indira Alsi-32, RLC-122 × Indira Alsi-32, R-4154 × Deepika
Plant height (cm)	R-4129 × Kartika, R-4154 × Indira Alsi-32, R-4154 × RLC-92, R-2678 × Kartika, , RLC-132 × RLC-92
Number of branches plant^{-1}	RLC-132 × RLC-92, R-4140 × Kartika, R-2678 × Deepika
Number of capsules plant^{-1}	R-2678 × Indira Alsi-32, R-4140 × Kartika, R-4152 × Indira Alsi-32
Number of seeds capsule^{-1}	R-2678 × RLC 92, R 4140 × Deepika
1000 seed weight (g)	RLC-132 × RLC-92, R-4129 × Kartika, RLC-122 × Indira Alsi-32
Oil content (%)	R-2678 × Kartika, R-4158 × Deepika, R-2678 × Indira Alsi-32
Harvest index (%)	RLC-132 × Kartika, R-2678 × Indira Alsi-32, R-4154 × Kartika
Seed yield plant^{-1} (g)	RLC-132 × RLC-92, R-4154 × Indira Alsi-32, R-4158 × Deepika, R-4129 × Kartika, RLC-132 × Kartika

Table 5: Heterobeltiosis (%) for seed yield and its component in linseed

Crosses (Hybrids)	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of branches plant^{-1}	Number of capsules plant^{-1}	Number of seeds capsule^{-1}	1000 seed weight	Oil content (%)	Harvest index (%)	Seed yield plant^{-1}
RLC-122 × Kartika	-8.21**	-14.08**	20.16**	66.45**	195.38**	-18.39**	-13.6**	-4.01**	19.69	25.54
RLC-122 × Deepika	17.27**	-7.32**	6.36	17.93	167.25**	6.48	15.6**	0.56*	12.91	65.25*
RLC-122 × Indira Alsi-32	3.63	-15.15**	5.50	10.33	58.28**	9.37	25.4**	1.73**	110.35**	112.35**
RLC-122 × RLC-92	-2.76	-1.97*	8.73	33.15	45.36**	-11.27	6.60	-1.49*	15.64	81.67**
RLC-132 × Kartika	18.10**	1.27	-6.43	25.18	65.32**	-1.56	14.8**	-4.13**	179.21**	335.67**
RLC-132 × Deepika	-5.96*	-5.38*	14.30**	23.08	82.34**	-7.35	-6.2*	-5.27**	120.64**	18.35
RLC-132 × Indira Alsi-32	-2.45	0.56	6.67	30.87	25.50	12.96	1.00	-7.50**	-64.51**	140.74**
RLC-132 × RLC-92	-16.14**	-8.22**	31.05**	138.47**	150.52**	-28.36**	50.2**	-3.10**	-45.35**	552.85**
R-2678 × Kartika	0.001	3.74	33.50**	33.64	141.36**	-3.65	3.50	4.40**	-51.34**	92.57**
R-2678 × Deepika	-9.75**	-4.53*	7.12	102.75**	71.07**	10.62	-11.5**	-8.63**	-9.11	180.57**
R-2678 × Indira Alsi-32	0.001	2.14	5.10	23.74	288.67**	14.71	-13.9**	2.89**	280.34**	130.58**
R-2678 × RLC-92	-2.57	0.63	-2.74	-8.54	21.35	18.75**	12.40	-4.42	74.75**	52.85*
R-4129 × Kartika	-14.55**	-8.22*	-27.32**	39.54	138.58**	-2.94*	36.7**	-1.70**	23.69	360.22**
R-4129 × Deepika	-2.65	0.28	4.32	27.58	17.68	0.93	4.90	-3.35**	41.35*	90.23**
R-4129 × Indira Alsi-32	2.64	-9.27**	-0.80	-20.30	48.23**	-17.57**	18.4**	-4.27**	78.95**	80.24**
R-4129 × RLC-92	-13.25**	-9.55**	5.58	13.10	67.25**	-0.52	0.80	-0.72*	85.64**	150.86**
R-4140 × Kartika	-12.44**	-14.75**	17.7**	124.89**	260.15**	-14.16	8.00	-6.00	90.65**	85.65**
R-4140 × Deepika	-2.87	-0.28	3.90	2.20	33.45	18.35**	-11.7**	-5.98**	65.16**	170.65**
R-4140 × Indira Alsi-32	3.75	-5.89*	-2.70	15.50	158.67**	15.23	5.00	-7.35**	-34.20**	65.12**
R-4140 × RLC-92	-2.70	0.78	-0.10	32.35	67.23**	-1.77	0.65	-3.85**	-10.35	85.24**
R-4141 × Kartika	-20.9**	12.47**	-10.7**	16.58	54.22**	0.68	-31.0**	-9.90	98.36**	97.65**
R-4141 × Deepika	1.90	-8.22**	18.36**	22.67	23.67	3.58	7.12	-8.25**	18.95	86.23**
R-4141 × Indira Alsi-32	-11.60	0.24	3.80	-9.78	30.15	6.52	8.63	-7.66**	35.12*	22.14
R-4141 × RLC-92	-7.90**	12.12**	9.56*	43.85	78.26**	6.21	2.35	-9.27**	12.57	7.40
R-4152 × Kartika	-23.40**	0.58	2.50	21.57	67.26**	8.75	-0.60	-9.51**	19.69	58.57*
R-4152 × Deepika	-10.90**	5.38*	6.76	7.14	185.25**	-7.65	1.26	-8.61**	70.25**	70.54**
R-4152 × Indira Alsi-32	-11.00**	0.67	18.8**	6.50	234.38**	-18.39**	8.35	-7.09**	87.58**	10.28
R-4152 × RLC-92	-10.40*	-11.28**	4.32	3.70	88.23**	6.57	18.5**	-6.71**	26.50	25.61
R-4154 × Kartika	14.20**	0.87	-3.00	51.35*	15.57	-3.20	21.54**	-2.55**	220.35**	65.37**
R-4154 × Deepika	-13.20	-15.10**	4.80	-4.35	20.18	7.59	7.65	-4.87**	91.50**	94.40**
R-4154 × Indira Alsi-32	15.40**	-15.3**	-23.36**	13.21	104.58**	11.23	17.5**	-2.75**	25.67	412.65**
R-4154 × RLC-92	-4.10*	3.15	-14.35**	31.70	94.36**	-2.56	2.50	-3.72**	150.35**	39.90
R-4158 × Kartika	31.50**	2.89	0.58	9.09	29.75	-3.68	3.70	-1.60*	-14.04*	29.80
R-4158 × Deepika	-9.80**	11.2**	30.90**	8.65	84.78**	13.54	-0.90	2.95**	22.67	385.75**
R-4158 × Indira Alsi-32	7.87*	1.16	3.40	-11.35	62.34**	-6.65	5.60	-5.69	115.94**	56.70*
R-4158 × RLC-92	0.40	2.74	-1.72	17.78	32.54	0.95	12.54*	-3.50**	-9.11	124.90**
R-4168 × Kartika	-4.50**	6.36*	-1.21	-47.68**	78.25**	-12.35*	3.50	-1.09*	97.35**	132.60**
R-4168 × Deepika	-3.50**	2.75	7.58	2.50	5.80	9.35	-11.8**	-3.99**	72.28**	48.69*
R-4168 × Indira Alsi-32	-5.90	5.35*	0.20	35.47	24.16	8.47	5.20	-4.17**	125.64**	142.60**
R-4168 × RLC-92	-3.70	3.16	-8.50*	-34.86**	94.60**	-6.58	-6.75*	-0.96*	80.35**	106.30**
SE(sij)	2.13	1.85	3.42	2.36	6.74	0.79	0.55	0.45	2.89	0.78

*, ** Significant at 5% and 1% level, respectively

and Rastogi (2007) and Singh *et al.* (2009). The promising hybrid combinations with significant specific combining ability effects are shown in Table 4.

Heterosis is the superiority of F_1 over the mean of the parents or over the better parent or over the standard check (Hayes *et al.,* 1956). Significant better parent heterosis in desired direction is used for selection of best hybrids. The heterobeltiosis for seed yield and its components are presented in Table 5.

Earliness in flowering and maturity is a highly desirable trait in linseed. Hence the crosses exhibiting heterosis in negative direction are of immense value. The hybrid R-4152 × Kartika showed highest negative heterosis for days to 50% flowering (-23.40%) and the cross R-4154 × Indira Alsi-32 showed highest negative heterosis for days to maturity (-15.30%) over better parent. Similarly, negative heterosis for plant height is desirable and it was observed in the cross R-4129 × Kartika (-27.32 %). Significant and positive heterobeltiosis was observed for number of branches plant^{-1} in the crosses RLC-132 × RLC-92, R-4140 × Kartika and R-2678 × Deepika, respectively. Similar findings were reported by Tak and Gupta, 1993.

Majority of the crosses showed significantly positive heterobeltiosis for number of capsules plant^{-1} ranging from 45.36 to 288.67 %. Out of them, crosses R-2678 × Indira Alsi-32, R-4140 × Kartika, R-4152 × Indira Alsi-32, RLC-122 × Kartika and R-4152 × Deepika were found to have high heterotic values. There were only two crosses *viz.* R-2678 × RLC-92 and R-4140 × Deepika showed significant positive heterobeltiosis for number of seeds capsule^{-1}. The cross RLC-132 × RLC-92 shown the maximum significant positive heterobeltiosis (50.2 %), while highest negative significant heterobeltiosis was observed for the cross R-132 × Deepika (-6.2 %) for 1000 seed weight. Significant and positive heterobeltiosis was observed for oil content in five crosses ranged from 0.56 to 4.40 %. The crosses R-2678 × Kartika followed by R-4158 × Deepika and R-2678 × Indira Alsi-32 exhibited higher heterebeltiosis for oil content (Singh *et al.*, 1983).

Improvement in seed yield, through heterosis in linseed, was one of the major aims of present investigation. Most of the crosses showed positive heterobeltiosis for seed yield. On an average 32 crosses exhibited significant positive heterobeltiosis, out of them 15 crosses exhibited more than 100% heterobeltiosis. Surprisingly, the values of heterobeltiosis ranging from 48.69 to 552.85 %. Five crosses consistently exhibited high values of heterobetliosis for higher seed yield plant^{-1}, namely RLC-132 × RLC-92, R-4154 × Indira Alsi-32, R-4158 × Deepika, R-4129 × Kartika and RLC-132 × Kartika indicating that these crosses might be useful in linseed hybrid production. Heterosis for yield was reflected through heterosis in yield components especially number of capsules plant^{-1} confirming the earlier findings of many workers reported high degree of heterosis for seed yield in linseed *viz.* Kansal and Gupta (1981), Dakhore *et al.* (1987), Rao *et al.* (1987), Saraswat *et al.* (1993), Verma and Mahto (1996), Foster *et al.* (1998), Kurt and Evans (1998), Rede (1999) and Reddy *et al.* (2013)

The results of the present investigation revealed that both additive and non additive gene effects were important in controlling various characters. The best combiners RLC-132, R-4129, Deepika and RLC-92 could be utilized in future breeding programmes while the crosses RLC-132 x RLC-92, R-4154 x Indira Alsi-32, R-4158 x Deepika, R-4129 x Kartika and RLC-132 x Kartika exhibited high heterotic effect for yield and its important attributes, might possibly be useful in heterosis breeding programmes for further improvement. It could be worth finding out whether superior crosses showing heterosis were also throwing out superior segregants.

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