Indian Journal of Agricultural Sciences **79** (3): 229–32, March 2009

Combining ability and heterosis for seed yield and oil content in linseed (*Linum usitatissimum*)*

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Received: 8 May 2008

Key words: Combining ability, Heterosis, Line×Tester, Linseed

Linseed (*Linum usitatissimum* L.) productivity in India continued to lag behind the world's average (846 kg/ha) despite development of 51 improved varieties and efficient agro-production and protection technologies. Constant efforts to improve yield through hybridization and selection of the parents are important in crop improvement programme. The line×tester mating design helps in realizing the precise estimate of the combining ability of the parents and thereby selecting superior parents as well as cross combinations. Accordingly, the present investigation was undertaken to elucidate the nature of combining ability and extent of heterosis for yield, its attributing characters and oil content in linseed.

Eight promising germplasm (lines), ie 'RAULD 7810', 'NPRR 482', 'RSJ2', 'NPRR 273', 'EC 3183', 'EC 1424', 'Belley' and 'Acc.No.2251' were crossed with 3 testers ('TL 11', 'TL 27' and 'TL 37') in a line×tester mating design to derive 24 hybrids during winter (*rabi*) 2005–06. National off-season nursery facilities available at IARI Regional Station, Wellington (TN) was availed to advance the 24 F_1s. The F_1 and F_2 generations of 24 crosses along with their 11 parents were grown in a randomized block design with 3 replications during *rabi* 2006–07 at Chandra Shekhar Azad University of Agriculture and Technology, Kanpur. The parents and F_1s were grown in single row, whereas F_2 populations in 4 rows of 5 m length with a row-to-row spacing of 30 cm. Recommended agronomic practices were followed to raise a good crop. Observations were recorded on 10 randomly selected plants from each parent and F_1 and 20 plants from F_2 populations in each replication for the 10 characters. The oil content (%) was estimated through NMR Oxford Model, MQA–7005. The data recorded on F_1s were analyzed as per the method suggested by Kempthorne (1957). Heterosis and residual heterosis were estimated as per standard procedure.

Table 1 ANOVA for combining ability in linseed

Source	df	Days to 50% flowering	Days to maturity	Plant height (cm)	Primary branches/ plant	Secondary branches/ plant	Capsules/ plant	Seeds/ capsule	1000-seed weight (g)	Oil content (%)	seed yield/ plant (g)
Replication	2	11.85	26.75	27.37	25.04	52.93	145.09	2.72	15.42	4.15	16.3
Females	7	10.05	55.26	351.64	20.50	733.93	2197.90	1.58	2.77	10.97	23.27
Males	2	14.89	1.93	7.54	54.29*	1157.76*	3126.21*	0.68	0.59	30.75**	10.63
F × M	14	21.87**	30.46**	257.20**	9.86**	286.90**	1054.09**	1.28*	1.26**	5.37**	20.89**
Error	46	2.19	1.12	1.44	1.28	3.16	4.63	0.62	0.13	1.15	0.46
GCA variance		–0.57	–0.11	–4.70	1.67	39.93	97.45	–90.81	0.025	0.94	–0.24
SCA variance		6.56	9.78	85.25	2.86	94.58	349.82	0.22	0.38	1.41	6.81
Average degree of dominance		–4.79	–13.33	–6.02	1.85	2.18	2.68	–0.07	5.51	1.73	–7.53

* $P = 0.05$, ** $P = 0.01$

The analysis of variance exhibited significant differences

*Short note

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Table 2 General combining ability effects of 11 parents for 10 characters in linseed

Parent	Days to 50% flowering	Days to maturity	Plant height (cm)	Primary branches/ plant	Secondary branches/ plant	Capsules/ plant	Seeds/ capsule (g)	1 000-seed wt. (%)	Oil content (g)	seed yield/ plant
Female										
'RAULD 7810'	–0.24	2.47**	–1.60**	0.14	6.00**	5.11**	0.17	–0.16	0.59*	–0.22
'NPRR 482'	–1.33**	–3.42**	–4.82**	0.69*	8.44**	–6.00**	0.50*	–0.20*	–0.45	–2.29**
'RSJ 2'	0.99**	–1.75**	–3.38**	0.92**	–0.67	11.67**	0.39	–0.46**	–1.09**	1.12**
'NPRR 273'	1.10**	–1.53**	0.62*	1.25**	6.78**	7.11**	0.06	0.59**	1.06**	2.81**
'EC 3183'	–0.46	0.92**	–5.60**	1.47**	5.33**	27.11**	–0.50*	0.88**	–1.72**	1.06**
'EC 1424'	–1.33**	–2.08**	–4.15**	–2.86**	–16.89**	–14.33**	–0.72**	0.42**	1.40**	–0.35
'Belley'	–0.01	2.47**	11.51**	–1.64**	–10.11**	–20.33**	0.17	–0.49**	0.71*	–0.78**
'Acc. No.2251'	1.32**	2.92**	7.40**	0.03	1.11*	–10.33**	–0.06	–0.58**	–0.49	–1.35**
Males										
'TL11'	0.61**	0.10	0.17	0.58**	4.28**	10.56**	–0.19	0.03	0.15	0.36**
'TL 27'	0.28	–0.32*	0.46**	1.13**	3.74**	1.56**	0.10	0.14**	1.05**	0.41**
'TL 37'	–0.89**	0.22	–0.62**	–1.71**	–8.01**	–12.11**	0.10	–0.17**	–1.20**	–0.77**
SE (females)	0.38	0.27	0.31	0.29	0.46	0.56	0.20	0.10	0.28	0.18
SE (males)	0.20	0.15	0.17	0.16	0.25	0.30	0.11	0.05	0.15	0.09
Correlation between GCA and parents (*per se*)	0.294	0.119	0.360	0.229	0.243	0.499	0.303	0.571	–0.092	0.145

* $P = 0.05$, ** $P = 0.01$

among the parents and hybrids for all the characters (Table 1). The parents vs. hybrids component was significant for most of the traits indicating the manifestation of heterotic response. Analysis for combining ability revealed that variance due to females was non-significant for all the traits whereas, variance due to males was significant for primary branches, secondary branches, number of capsules and oil content thereby indicating their divergence and also satisfied the choice of testers.

Higher estimate of SCA variance was observed for almost all the traits reflecting greater role of non-additive type of gene action in expression of these traits. The mean degree of dominance was more than unity for all the characters under investigation confirming the above inference. These results are akin to the earlier reports (Tiwari *et al.* 2004, Bhateria *et al.* 2006, Rao and Rastogi 2007). It is important to mention that the estimates of GCA and SCA variances are relative and depend upon the set of parental materials. Hence should always be kept in mind while interpreting the results on combining abilities.

General combining ability (GCA) effects for parental lines revealed that none of the eleven parents showed desirable significant GCA effects for all the traits (Table 2). The female parents identified as good general combiners for earliness and dwarfness were 'NPRR 482', 'EC 1424' and 'EC 3183', 'EC 1424', 'NPRR 482', 'RSJ 2', 'RAULD 7810', respectively. Among the males, 'TL27'was good general combiner for days to maturity, primary branches, secondary branches, number of capsules, 1 000–seeds weight, oil content and seed yield/plant. In general, it was observed that the parents 'NPRR 273', 'RSJ 2' and 'EC 3183'were superior general combiner for seed yield/plant and other important traits. For oil content 'EC 1424' was the best general combiner. There was no correlation between *per se* performance and GCA effects of the parents for the traits studied. In such situation, selection has to be performed both for GCA and SCA, though their relative contribution towards improvement would be determined by the proportion of additive and non-additive variances in the base population.

The estimate of SCA effect for seed yield/plant was significant for 6 crosses. The 5 top crosses selected on the basis of SCA effects, *per se* performance, heterosis and residual heterosis for seed yield and oil content have been presented in Table 3. In general significant association between SCA effects and cross mean was observed. Cross 'NPRR 273'×'TL 37' exhibited significant SCA effects for six traits (days to 50% flowering, days to maturity, primary branches, number of seeds, 1 000-seed wt. and oil content) in addition to seed yield/plant whereas 'EC 3183'×'TL 37' was found to have significant SCA effects for primary branches and seed yield/plant.

Majority of the crosses with significant SCA effects involved the parents having one good and one poor combiner for all the characters except 'RSJ 2'×'TL 27', 'RSJ 2'×'TL 11', 'EC 3183'×'TL 27', 'EC 3183'×'TL 11' and 'NPRR 273'×'TL 27' involving good×good combiners indicating the significance of non-additive gene action. Such crosses involving good combining parents can be considered for development of superior varieties through pedigree method. High SCA effects of good×poor GCA combinations might be due to complementary non-additive interallelic interactions and hence, suitable for heterosis breeding.

Table 3 Five most superior crosses selected on the basis of SCA effects, *per se* performance, heterosis and residual heterosis for seed yield and oil content in linseed

Sca effect	GCA Effect	Mean	Heterosis (BP)		Residual Heterosis (BP)	
Oil content (%)'						
'RAULD 7810× TL 37' (2.08)**	hxl	'Belley×TL 27' (42.50)	'EC 1424×TL 11'	16.68**	'EC 1424 x TL 11'	17.76**
'NPRR 273× TL 37' (1.95)**	hxl	'EC 1424×TL 27' (42.17)	'RAULD 7810×TL 37'	5.79**	'NPRR 482×TL 11'	6.52**
'EC 3183× TL 27' (1.25)**	lxh	'EC 1424×TL 11' (41.90)	'NPRR 482×TL 11'	3.41**	'EC 1424×TL 37'	6.03**
'Belley× TL 27' (0.85)**	hxh	'NPRR 273×TL 37'(41.70)	'EC 1424×TL 37'	3.32**	'EC 3183×TL 37'	5.54**
'NPRR 482× TL 11' (0.79)**	lxl	'Belley×TL 11' (41.52)	'Belley×TL 27'	2.45**	'Acc. No.2251×TL 37'	5.27**
Corr. between SCA and crosses		0.59**				
Seed yield per plant						
'EC 1424×TL 27' (4.41)**	lxh	'RSJ2×TL 27' (15.39)	'RSJ 2×TL 27'	102.37**	'RSJ 2×TL 11'	47.61**
'RAULD 7810× TL 11' (4.06)**	lxh	'EC 1424×TL 27' (14.67)	'EC 1424×TL 27'	96.87**	'NPRR 273×TL 27'	10.54**
'RSJ2× TL 27' (3.65)**	hxh	'NPRR 273×TL 37' (14.65)	'NPRR 273×TL 37'	45.16**	'EC 1424×TL 37'	6.11**
'NPRR 273× TL 37' (2.41)**	hxl	'RAULD 7810×TL11' (14.40)	'RSJ 2×TL 11'	43.36**		
'EC 3183× TL 37' (1.79)**	hxl	'NPRR 273×TL 11' (13.39)	'RAULD 7810×TL 11'	37.84**		
Corr. between SCA and crosses		0.78**				

* $P = 0.05$, ** $P = 0.01$

Heterosis was also calculated as per cent increase or decrease over mid parent and corresponding better parent. It was interesting to observe higher level of residual heterosis for oil content in crosses 'EC1424'× 'TL11', 'NPRR482'× 'TL-11' and 'EC1424'×'TL37' which might be due to accumulation of favourable alleles in F_2 generation. Subsequently these three crosses can be utilized to develop pure lines as good as hybrids or better than hybrids for oil content. It was observed that crosses having poor×good general combiners produced heterotic hybrids. These findings were in accordance with the earlier reports of Kumar *et al.* 2002, Tiwari *et al.* 2004, Ratanparkhi *et al.*2005, Rao and Rastogi 2007.

Thecross 'RSJ 2'×'TL 27' was found potential for the development of improved varieties of linseed by adopting pedigree method of breeding whereas, for the remaining good×poor GCA crosses, a suitable population improvement such as intermating of F2 segregants, followed by recurrent selection would be appropriate to exploit the non-additive gene action.

SUMMARY

Combining ability analysis was carried out in linseed during 2006–07 following line×tester design for 10 quantitative characters using 8 females and 3 males. 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. 'NPRR 273', 'RSJ 2' and 'TL 27' were good general combiners for seed yield and its related attributes. Correspondence between SCA effects and crosses mean was observed, while it was absent between GCA effects and parental mean. Higher level of residual heterosis in three crosses 'EC 1424'×'TL 11', 'NPRR 482'×'TL 11' and 'EC 1424'×'TL 37' was recorded for oil content. In general crosses originating from poor×good general combiners produced heterotic hybrids with substantial SCA effects. Five crosses 'RSJ 2'×'TL 27', 'EC1424'×'TL 27', 'NPRR 273'×'TL 37', 'RAULD 7810'×'TL 11' and 'EC3183'×'TL 37' were most promising having good SCA effects for seed yield / plant and considered potential for the development of improved varieties of linseed.

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