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Combining ability analysis in linseed (*Linum usitatissimum* L.) for improvement of seed yield and its component traits in early sown normal irrigated condition in South Eastern zone of Rajasthan

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Abstract
The experiment comprised twenty eight hybrids developed from eight genotypes of linseed through diallel mating design (excluding reciprocal) along with checks were evaluated in randomized block design under early sown in normal irrigated condition with three replications for twelve distinct morphological characters, during *Rabi* season of 2019-20, to estimate the general combining ability (GCA) of the parents and specific combining ability (SCA) of hybrids. Significant General Combining Ability (GCA) and Specific Combining Ability (SCA) effects were noted for all the traits except GCA for number of secondary branches per plant and biological yield per plant. PA2 and RL15583 displayed positive GCA effects for seed yield per plant. Among these parents PA2 displayed positive significant GCA effect for number of primary branches per plant, test weight and harvest index and RL15583 also showed desirable significant GCA effects for days to 50% flowering, number of capsules per plant, number of seeds per capsule and harvest index. Among 28 crosses, 6 (Padmani x PA2, RL15582 x PA2, RL15583 x KBA3, RL15583 x KBA4, RL15583 x RL13161, and RL15583 x RL15582) involving at least one parent with good GCA effect for seed yield per plant and at least one component of seed yield, are expected to throw higher frequency of desirable segregants to develop high yielding linseed varieties.

Keywords: combining ability, linseed, GCA, SCA, seed yield

Introduction
Linseed (*Linum usitatissimum* L.) is a multipurpose oilseed crop mostly cultivated in *Rabi* season. It is extensively used for its seed, oil, cake and stem for good quality fibre and also as an ingredient in indigenous medicines for treating the diseases of human and animal. Oil is now being extensively used in industrial purpose like paints, varnish, leather, lubricants and in paper printing industries. India ranks second in terms of area after Canada. In terms of production, it occupies fourth place after Canada, China and USA, respectively. In India, it is grown in about 3.592 lakh ha area, contributing 1.465 lakh tonnes to the annual oilseed production of the country (Anonymous, 2013) [1].

Plant breeders are ever engaged to improve genetic potential of linseed to achieve higher linseed yield for confronting challenges of environmental stresses. Several plant breeders have successfully employed combining ability analysis of griffing (khan *et al*. 1999) [3] to determine the genetic worth of parents and employing appropriate selection procedures in desirable crosses. The concept of combining ability is important in crop improvement because it allows breeders to compare and examine the performance of new lines in hybrid combinations. It serves as a foundation for choosing suitable combiners as well as for learning how to use them comprehends the mechanism of gene activity Furthermore; the use of heterosis is mostly reliant on the construction of high-performing lines that are also good at what they do widespread ability to combine. Present study was designed to collect the information on combining ability in a set of potential linseed genetic stock for further utilization in breeding programme and emphasized to develop high yielding linseed genotypes.

Materials and Methods
The experimental material comprised of eight promising lines viz., PA 2, KBA3, KBA4, RL13161, Padmani, RL15582, RL15583 and Meera of linseed, which were crossed diallel fashion to generate 28 F1s.

The seeds of 36 entries (8 parents and 28 F1s hybrids) were sown in the field using a Randomized Complete Block Design with three replications during Rabi, 2019- 20 as early planting in 25th September, 2020. 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 diseases and pest free crop. Five randomly selected competitive plants from each row were used to record the biometric observations of plant height (PH), number of primary branches per plant (PBPP), number of secondary branches per plant (SBPP), number of capsules per plant (CPP), number of seeds per capsule (SPC), biological yield per plant (BYPP) and seed yield per plant (SYPP). But days to 50 per cent flowering (DF), days to maturity (DM), test weight (TW), oil content (OC), was recorded on whole row basis. The biochemical analysis was done for oil content by Soxhlet procedure as described in AOCS.

The mean values of five plants for twelve traits were subjected to analysis of variance proposed by Steel and Torrie (1980) [8] and the estimates of combining ability were made by applying Griffing (1956) [2] method-II (Model-2).

Results and Discussion

Mean squires due to genotypes, GCA and SCA for twelve traits presented in table 1 and 2. Highly significant mean squares due to genotypes (parents and hybrids) indicated that considerable genetic diversity was present in the experiment for all twelve characters. Mean square due to both GCA and SCA were significant for seed yield and all other component characters except number of secondary branches per plant and biological yield per plant indicating importance of both additive and non additive gene effects in their inheritance. Non significant GCA and significant SCA were observed indicated that these traits are controlled by non additive gene effects.

The magnitude of σ^2 was greater than σ^2 for all the traits indicating that the expression of these traits is governed by non additive gene action. The ratio of GCA and SCA variance (model 1) presented in table 2 obtained were less than unity (<1) also indicating the importance of non additive genetic variance in expression these traits. Therefore non additive genetic variance was more important for seed yield and its all attributing traits under study. Among these traits the selection is rewarded in later generations as suggested by Khan *et al*. (1999) [3].

None of the parents tested was a good general combiner for all the characters in desired direction. High mean performance as compare to mean of parents and significant positive GCA effects (Table 3) in case of PA2 and RL15583 for seed yield per plant and its components viz., PA2 for number of primary branches per plant, test weight and harvest index and RL15583 for desirable days to 50 percent flowering, number of capsules per plant, number of seeds per capsule and harvest index. It was observed by Khan *et al*. (1999) [3] that, crosses involving parents with high individual GCA effects produced a high percentage of superior yielding progeny in subsequent generations. PA2 and RL15583 with positive GCA effects for seed yield could be useful for further breeding.

SCA effects were positive significant in 13 crosses (Table 4) for seed yield per plant, in 3 crosses for days to 50 percent flowering, in 7 crosses for days to maturity, in 8 crosses for plant height, in4 crosses for number of primary branches per plant, in 4 crosses for number of secondary branches per plant, in 10 crosses for number of capsules per plant, in 8 crosses for number of seeds per capsule, in 14 crosses for test weight, in 7 crosses for oil content, in 6 crosses for biological yield per plant and in 3 crosses for harvest index.

In contrast to GCA effects, the SCA effects represents dominance and epistatic components of variation which are non fixable in nature (Griffing 1956, Mishra and Rai 1956 and Khan *et al*. 1999) [2, 4, 3]. These investigations also provided evidence that if crosses showing high SCA effects involve both or one of high combining parents, they could be successfully exploited for varietal improvement and expected to throw superior transgressive segregants. Among 28 crosses studied 6 crosses involving at least one parent with good GCA effect *i.e*. PA2, RL15582. Padmani x PA2, RL15582 x PA2, RL15583 x KBA3, RL15583 x KBA4, RL15583 x RL13161, and RL15583 x RL15582 depicted positive SCA effects for seed yield and for at least seed yield component. These crosses are expected to generate relatively higher degree of desirable segregants compare to other seven. Since the SCA effect of the cross is an estimated for making selection of best cross combinations, high specific combining ability denotes undoubtedly a high heterotic response, this however, does not mean high performance of the hybrid as well as. The above findings less or more closely in agreement with the results of Mishra and Rai, 1996 [4], Singh *et al*. 2008 [7] and Shekhar *et al*. 2019 [6].

Table 1: Analysis of variance for diallel crosses for seed yield and its component characters in linseed.

Source of variation	D.F.	Mean sum square											
		DF	**DM**	**PH**	**PBPP**	**SBPP**	**CPP**	**SPC**	**TW**	**OC**	**BYPP**	**SY**	**HI**
Replication	2	1.81	1.78	14.79	0.03	24.78	183.85	0.22	0.03	0.09	21.48	0.53	23.72
Genotypes	35	29.48**	41.66**	65.32**	0.67**	44.02**	1124.68**	1.72**	1.92**	7.60**	59.04**	3.70**	31.47**
Parents	7	53.99**	57.57**	152.65**	0.77**	22.06	1135.80**	1.27**	1.04**	15.34**	7.41	0.74**	15.87
Crosses	27	22.82**	30.87**	40.73**	0.55**	32.86*	578.06**	1.90**	1.55**	5.30**	32.95**	2.32**	36.68**
Parents v/s Crosses	1	37.78**	221.72**	118.15**	3.02**	494.84**	15805.31**	0.01	18.03**	15.30**	1124.87**	61.54**	0.11
Error	70	3.53	2.67	4.43	0.17	19.50	80.12	0.17	0.09	0.80	12.64	0.20	11.54

*, ** significant at 5% and 1% level, respectively.

Table 2: Analysis of variance and estimates of components of variance for combining ability for seed yield and its component characters in linseed.

Source of variation	D.F.	Mean sum square											
		DF	DM	PH	PBPP	SBPP	CPP	SPC	TW	OC	BYPP	SY	HI
GCA	7	40.02**	38.08**	77.16**	0.54**	**6.24**	520.99**	0.27**	0.87**	4.50**	5.63	0.95**	19.54**
SCA	28	2.28*	**7.84****	7.93**	0.14**	16.78**	338.37**	0.65**	0.58**	2.04**	23.19**	1.30**	8.23**
Error	70	1.18	0.89	1.48	0.06	6.50	26.77	0.06	0.03	0.27	4.21	0.07	3.85
Components of variance													
σ2 g		4.20	4.34	8.83	0.06	-0.03	57.66	0.02	0.10	0.49	0.17	0.10	1.83
σ2 s		20.44	32.43	30.11	0.40	47.98	1494.10	2.76	2.58	8.28	88.58	5.78	20.45
σ2 2g / σ s		0.21	**0.13**	0.29	0.15	0.00	0.04	0.01	0.04	0.06	0.00	0.02	0.09

*, ** significant at 5% and 1% level, respectively.

Table 3: Estimates of general combining ability (GCA) effect for seed yield and its component characters in linseed.

Parents	DF	DM	PH	PBPP	SBPP	CPP	SPC	TW	OC	BYPP	SY	HI
PA 2	2.88**	0.27	3.81**	0.37**	-0.65	-8.85**	0.02	0.53**	-0.79**	-0.16	0.39**	1.31*
KBA 3	0.05	-0.99**	0.77*	-0.16*	0.55	-5.47**	0.00	-0.37**	0.06	0.64	-0.32**	-1.59**
KBA 4	0.72*	-0.79**	-1.48**	0.11	0.27	7.75**	-0.29**	0.05	0.90**	0.85	0.05	-0.69
RL13161	0.85**	-0.36	0.42	-0.06	-1.07	-4.96**	0.13	-0.01	0.47**	0.72	-0.13	-1.05
Padmani	-3.02**	-2.16**	-3.85**	-0.42**	1.51*	-1.96	0.01	0.14**	0.76**	-0.09	-0.43**	-1.41*
RL15582	-2.28**	-0.39	-2.98**	0.06	-0.30	-1.91	0.05	-0.40**	-0.30	0.09	0.09	0.12
RL15583	-0.98**	-0.06	-0.25	0.14	-0.19	12.49**	0.24**	-0.02	-0.22	-0.74	0.44**	2.11**
Meera	1.78**	4.47**	3.57**	-0.03	-0.11	2.92	-0.16*	0.09	-0.88**	-1.31*	-0.08	1.20*
SE (gi)	0.32	0.28	0.36	0.07	0.75	1.53	0.07	0.05	0.15	0.61	0.08	0.58
SE (gi-gj)	0.49	0.42	0.54	0.11	1.14	2.31	0.11	0.08	0.23	0.92	0.11	0.88

*, ** significant at 5% and 1% level, respectively.

Table 4: Estimates of specific combining ability (SCA) effect for seed yield and its component characters in linseed.

Crosses	DF	DM	PH	PBPP	SBPP	CPP	SPC	TW	OC	BYPP	SY	HI	Per se yield
KBA 3 x PA2	-2.62**	1.69	3.69**	-0.06	-1.12	9.21	0.75**	-1.58**	1.02*	-1.57	-0.40	0.09	5.90
KBA 4 x PA2	-4.29**	-6.51**	0.06	-0.08	-2.18	-0.28	1.33**	0.66**	-0.76	1.23	0.12	-0.71	6.98
RL13161x PA2	-0.09	-3.94**	1.12	-0.12	-2.51	-7.04	0.42	0.34*	0.27	-0.06	0.23	0.57	6.72
Padmani x PA2	-0.22	-3.48**	0.71	-0.15	2.58	0.14	-0.21	0.99**	0.55	4.18*	1.16**	0.28	7.35
RL15582 x PA2	1.71	0.09	-2.17	-0.04	5.39*	9.71*	-1.60**	0.30	-0.31	2.24	0.73**	0.39	7.45
RL15583 x PA2	1.75	-3.58**	-4.65**	0.23	-1.38	-2.36	-1.00**	1.05**	0.56	4.88*	0.35	-3.13	4.41
Meera x PA2	-0.69	1.56	-4.69**	0.46*	-0.07	0.80	0.18	-0.32*	1.32**	-4.20*	0.52*	6.10**	7.07
KBA 4 x KBA 3	-0.45	-0.58	-0.36	0.63**	3.96	13.82**	0.06	0.34*	1.20*	2.55	0.92**	0.91	7.51
RL13161 x KBA 3	0.75	-1.01	-1.09	0.38	5.63*	27.12**	-0.38	0.11	-0.89	10.88**	1.51**	-2.25	7.30
Padmani x KBA 3	0.61	-0.88	-1.38	-0.24	2.38	13.97**	0.14	-0.20	-0.24	-0.24	0.42	2.09	6.97
RL15582 x KBA 3	-0.12	-0.31	-2.59*	-0.07	-0.47	-13.99**	0.53*	-0.50**	0.82	0.59	-0.98**	-3.67*	5.03
RL15583 x KBA 3	0.25	-1.98*	-2.79*	-0.21	-2.92	21.20**	-2.01**	0.89**	0.67	1.47	1.63**	3.83*	7.98
Meera x KBA 3	1.15	-1.51	-0.60	-0.13	-2.00	8.84	0.10	0.70**	0.71	-3.07	-0.64**	0.39	5.19
RL13161 x KBA 4	0.75	-0.54	0.46	-0.22	3.24	7.02	-0.15	0.50**	0.72	1.36	0.27	-0.08	6.43
Padmani x KBA 4	-1.72	0.26	-3.41**	0.58**	5.99*	-6.50	-0.44*	-0.50**	1.34**	1.99	-0.20	-2.05	7.47
RL15582 x KBA 4	0.21	0.16	0.67	-0.26	-3.19	22.45**	0.09	0.85**	1.19*	2.70	1.47**	2.36	8.02
RL15583 x KBA 4	-0.09	1.82*	1.12	0.33	6.36**	17.77**	-0.36	0.70**	-0.42	2.21	1.14**	1.54	7.87
Meera x KBA 4	1.15	-0.38	-1.62	0.04	-0.79	-2.71	-0.21	0.43**	-2.50**	5.35**	-0.45	-5.45**	5.77
Padmani x RL13161	-0.19	1.82*	-3.64**	0.06	3.42	21.54**	-0.79**	0.23	-1.08*	-1.34	-0.96**	-2.41	6.90
RL15582 x RL13161	-0.59	0.72	-0.74	-0.22	-3.19	14.93**	0.49*	0.05	0.05	1.80	0.40	0.35	6.60
RL15583 x RL13161	-0.55	0.72	0.62	0.55*	3.49	3.81	0.49*	-0.22	-3.71**	-1.95	1.08**	5.23**	8.09
Meera x RL13161	-0.65	-1.14	0.92	0.11	2.02	-0.00	0.50*	0.34*	1.40**	3.00	1.07**	1.30	7.10
RL15582 x Padmani	-1.05	0.86	4.45**	0.92**	-0.43	4.83	-0.12	0.06	1.25**	3.06	0.72**	-0.12	6.62
RL15583 x Padmani	-0.35	-1.14	2.18	-0.14	3.29	-3.24	0.75**	0.66**	-0.75	4.88*	-0.30	-4.35*	5.95
Meera x Padmani	0.88	-3.34**	-2.91*	-0.22	1.07	1.33	0.72**	0.38*	0.04	2.38	0.65**	-0.38	6.38
RL15583 x RL15582	-1.09	-0.91	3.18**	0.39	0.72	19.19**	1.48**	0.00	0.68	1.07	0.68**	1.15	8.77
Meera x RL15582	-2.19*	-2.78**	0.45	-0.05	2.34	4.95	0.19	0.11	0.50	4.23*	0.17	-3.33	6.43
Meera x RL15583	-1.15	2.89**	-2.63*	0.03	0.41	-5.45	-1.07**	-0.25	1.98**	-1.30	-0.01	1.83	6.59
SE (sij)	0.98	0.86	1.10	0.22	2.31	4.69	0.22	0.16	0.47	1.86	0.23	1.78	
SE(Sij-ik)	1.46	1.27	1.63	0.32	3.42	6.94	0.32	0.23	0.69	2.75	0.34	2.63	

*, ** significant at 5% and 1% level, respectively.

Table 5: Mean value (per se performance) of parents for seed yield and its component characters in linseed.

Parents	DF	DM	PH	PBPP	SBPP	CPP	SPC	TW	OC	BYPP	SY	HI
PA 2	62.67	135.67	70.00	6.11	27.57	94.91	7.57	8.16	38.00	27.27	5.66	0.21
KBA 3	57.67	123.67	56.00	4.41	27.60	66.36	7.88	7.19	40.33	29.38	4.15	0.14
KBA 4	55.00	126.67	51.67	4.59	23.07	103.92	6.73	6.43	42.93	23.01	4.80	0.21
RL13161	59.33	124.00	55.67	4.96	21.03	73.77	7.43	7.13	43.50	24.59	3.91	0.16
Padmani	53.33	125.67	48.67	5.30	23.10	97.43	7.47	7.28	43.73	22.38	5.30	0.24
RL15582	54.33	125.00	49.33	5.22	28.03	82.52	7.05	6.58	43.50	22.35	3.82	0.17
RL15583	56.00	130.00	53.67	5.55	23.87	111.71	8.80	6.37	40.97	23.08	5.22	0.23
Meera	62.67	133.33	74.33	5.33	27.52	119.33	6.93	7.30	40.77	28.62	5.70	0.20
mean (parents)	57.63	128.00	57.42	5.18	25.22	93.74	7.48	7.05	41.42	25.08	4.82	0.19

*, ** significant at 5% and 1% level, respectively.

Conclusion

Combining ability analysis in the present study provided useful information on the prepotency of linseed genotypes and identified PA2 and RL15583 as useful progenitor for the development of better yielding varieties. And cross RL15583 x KBA3 was identified as most promising cross for seed yield and its components based on SCA effects.

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