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GENETICS AND PLANT BREEDING

Combining Ability Analysis for Seed Yield and its Contributing Traits in Indian Mustard [*Brassica juncea* (L.) Czern & Coss.]

P.K. Chaudhary[1], P.T. Patel[2], K.P. Prajapati[3], J.R. Patel[3*], P.J. Patel[3] and B.K. Patel[3]

[1]Department of Genetics and Plant Breeding, C.P. College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat, India
[2]Pulse Research Station, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat, India
[3]Castor-Mustard Research Station, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat, India

*Corresponding author: pateljignesh212@gmail.com (**ORCID ID:** 0000-0002-7931-4146)

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ABSTRACT

A set of 10 × 10 diallel crosses (excluding reciprocals) of Indian mustard along with their parents were evaluated to estimate general and specific combining ability of parents and crosses, respectively. The analysis of variance for combining ability revealed that variance due to *gca* was significant for all the characters except lenoleic acid and erucic acid. Whereas, variance due to *sca* was significant for all the traits except plant height, lenoleic acid and erucic acid. Magnitude of variance components of *sca* were higher than *gca* (*gca*/*sca*) for all the traits except plant height, oleic acid and erucic acid indicated preponderance of non-additive gene action for these traits. The estimates of general combining ability effects indicated that parents GM 1 and GM 2 were good general combiners for seed yield per plant and most of the yield attributing traits. Parents, SKM 9033, RSK 28 and GDM 4 for oil content, P. Mustard 21 and LES 45 for oleic acid, P. Mustard 21 and Dhara for lenoleic acid and P. Mustard 21 and LES 45 for erucic acid were found good general combiners. Cross combinations *viz.*, GDM 4 × Dhara, SKM 9033 × RSK 28, GM 3 × LES 45, GDM 4 × EC 287711 and GM 1 × P. Mustard 21 were found good specific combinations for seed yield per plant and other desirable traits. Thus these cross combinations could be utilized in breeding programme for further amelioration of seed yield in Indian mustard.

Highlights

- Parents GM 1 and GM 2 were good general combiners for seed yield per plant and most of the yield attributing traits.
- Cross combinations *viz.*, GDM 4 × Dhara, SKM 9033 × RSK 28, GM 3 × LES 45, GDM 4 × EC 287711 and GM 1 × P. Mustard 21 were found good specific combinations for seed yield per plant and other desirable traits.

Keywords : Diallel, Combining ability, Gene action and Indian Mustard

Indian mustard is an important *rabi* season oilseed crop in India and occupies a premier position among the oilseed crops. It is popularly known as *rai*, *raya* or *laha* in India. It plays a major role in catering to edible oil demand of the country. The genus *Brassica*, belongs to *cruciferae* or *brassicaceae* family. Indian mustard is a natural amphidiploids (2n = 36) of *Brassica rapa* (2n = 20) and *Bassica nigra* (2n = 16). Mustard is largely self-pollinated crop. However, certain amount of cross pollination of 5 to 18 per cent may take place as a result of honeybee. (Labana and Banga 1984). Rajasthan is the largest producer of rapeseed-mustard followed by Uttar Pradesh, Haryana, Madhya Pradesh, West Bengal, Gujarat and Assam. In Gujarat mustard cultivated in about 2.01 lakh hectares with the production of 3.44 lakh tonnes and productivity of 1710 kg/ha (Anonymous, 2016). In Gujarat it is mostly grown in Mehsana, Patan, Banaskantha, Sabarkantha, Gandhinagar, Kutch and Ahmedabad districts.

Evaluation of breeding material for general and specific combining ability for seed yield and yield contributing characters is prerequisite in any breeding programme aimed for the development of hybrids. The combing ability also provides information about the nature and magnitude of gene action involved in the expression of various quantitative characters.

Diallel mating design has been extensively used in self and cross pollinated species to understand the nature of gene action involved in the expression of quantitative traits. It yields reliable information on the components of variance and *gca* and *sca* variances and their effects. Thus, it helps in the selection of suitable parents for hybridization as well as in the choice of appropriate breeding procedures (Griffing, 1956). Therefore, the present investigation was undertaken with an objective to assess the nature of gene action involved and combining ability of parental genotypes for various traits for evolving productive varieties in Indian mustard.

MATERIALS AND METHODS

Ten Parents were crossed in diallel mating design (excluding reciprocal) at Agronomy Instruction Farm, C. P. College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar (Gujarat) during *rabi* 2012-13. All the genotypes (45 hybrids and 10 parents and one check) were grown in a Randomized Block Design with three replications during *rabi* 2013-14. Each genotype was sown in a single row of 2.0 m length with a spacing of 45 cm between rows and 15 cm plant to plant. The guard rows were provided on all the sides of each block. All recommended agronomical and plant protection measures were followed to raise healthy crop. Data were recorded on five randomly selected plants from each net plot of parents and F_1s in all the three replications. Mean value on per plant basis were recorded for various characters *viz*., plant height (cm), number of branches per plant, number of silique per plant, seed yield per plant (g), 1000 seed weight (g), harvest index (%), oil content (%), oleic acid, lenoleic acid and erucic acid content, while for days to flowering and days to maturity observations were recorded on plot basis. The mean data was analysed to compute combining ability effect and their variance according to Griffing (1956) as per method II and Model I.

RESULTS AND DISCUSSION

The analysis of variance for combining ability (Table 1) revealed that mean square due to general combining ability and specific combining ability were significant for days to flowering, days to maturity, number of branches per plant, number of siliquae per plant, seed yield per plant, 1000 seed-weight, harvest index, oil percentage and oleic acid content. The variance due to *sca* was higher than that of due to *gca* for all the characters except plant height, oleic acid and erucic acid under study indicated the predominance role of non-additive gene action. These results were in agreement with the studies of Rahman *et al.* (2011), Dar *et al.* (2011) and Pandey *et al.* (2013).

Nature and magnitude of combining ability effects helps in identifying superior parents and their utilization in further breeding programme. An overall appraisal of general combining ability effects of parent (Table 2) revealed that the parent GM 2 was found good general combiner for all the yield contributing traits. The parent GM 1 was good general combiner for all the traits except number of silliquae per plant and oil content. For qualitative traits parent SKM 9033, RSK 28 and GDM 4 were found to be good general combiner for oil content. Similarly P. Mustard 21 and LES 45 for oleic acid and erucic acid, while P. Mustard 21 and Dhara for lenoleic acid were found good general combiners. In general, it was evident from Table 2 that the parents which were good general combiners for seed yield per plant were also good general combiners for some of its yield contributing traits like number of branches per plant, number of silliquae per plant and 1000 seed weight. Similar results were also reported by Singh *et al.* (2005), Patel *et al.* (2012) and Gami and Chauhan (2013). Therefore the parents GM 1 and GM 2 can be considered as a good source of favourable genes for increasing seed yield along with other yield attributes. Thus, it would be worthwhile to use these parental lines in hybridization programme.

The estimate of specific combining ability effects were presented in Table 3 revealed that as many as thirteen cross combinations exhibited significant and positive *sca* effects for seed yield per plant.

Table 1: Analysis of variance (mean square) for combining ability and estimates of components of variance for twelve characters in Indian mustard

Source of variations	d.f.	Days to flowering	Days to maturity	Plant height (cm)	No. of branches per plant	No. of silique per plant	Seed yield per plant (g)	1000-seed weight (g)	Harvest index (%)	Oil content (%)	Oleic acid (%)	Lenoleic acid (%)	Erucic acid (%)
GCA	9	89.58**	40.58**	332.34**	17.23**	1148.40**	75.63**	1.23**	192.53**	13.58**	274.87**	42.51	676.20
SCA	45	17.86**	11.76**	40.47	10.11**	1289.72**	29.10**	0.20**	25.04**	3.49**	15.87**	9.12	35.22
Error	108	0.83	4.13	61.34	0.94	217.46	1.99	0.04	2.5	0.43	0.04	0.05	0.06
$\sigma^2 gca$		7.40	3.04	22.58	1.36	77.58	6.14	0.10	15.84	1.10	22.90	3.54	56.35
$\sigma^2 sca$		17.03	7,63	-20.87	9.17	1072.27	27.11	0.16	22.54	3.06	15.83	9.07	35.16
$\sigma^2 gca / \sigma^2 sca$		0.43	0.40	-1.08	0.15	0.07	0.23	0.62	0.70	0.36	1.45	0.39	1.60

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

Table 2: Estimates of general combining ability (*gca*) effects of the parents for twelve characters in Indian mustard

Sl. No.	Parents	Days to flowering	Days to maturity	Plant height (cm)	No. of branches per plant	No. of siliquae per plant	Seed yield per plant (g)	1000-seed weight (g)	Harvest index (%)	Oil content (%)	Oleic acid (%)	Lenoleic acid (%)	Erucic acid (%)
1	GM 1	-1.74**	-3.33**	-10.46**	0.88**	3.38	2.25**	-0.23**	7.93**	0.10	-3.84**	-1.30**	7.29**
2	GM 2	-3.99**	-2.36**	-4.98*	2.50**	12.37**	4.67**	0.45**	3.79**	-0.62**	-3.90**	-0.46**	5.68**
3	GM 3	-2.41**	0.53	0.81	-0.27	-9.14*	1.20**	0.46**	-0.38	0.04	-3.97**	-0.41**	5.68**
4	GDM 4	-2.33**	-1.13*	-4.23	0.37	3.93	1.32**	0.04	3.26**	0.41*	-2.68**	-1.77**	4.89**
5	LES 45	3.84**	1.45*	3.73	0.15	10.83**	-0.18	0.35**	-2.52**	-0.89**	6.81**	0.88**	-9.24**
6	P. Mustard 21	3.01**	1.09	6.97**	0.004	4.90	-0.30	-0.20**	-5.24**	-1.94**	8.90**	3.83**	-13.32**
7	Dhara	0.03	-0.22	4.61*	-2.24**	-21.09**	-4.23**	-0.50**	-3.99**	-0.29	4.00**	2.46**	-8.41**
8	EC 287711	3.59**	2.84**	2.04	-0.47	-1.53	-1.34**	-0.21**	-1.66**	0.12	-1.00**	-0.02	0.06
9	SKM 9033	0.39	0.89	2.68	-0.52	-3.00	-0.91*	-0.10	-1.88**	1.87**	-1.34**	-1.43**	2.26**
10	RSK 28	-0.38	0.23	-1.17	-0.41	-0.64	-2.47**	-0.07	0.68	1.21**	-2.98**	-1.77*	5.22**
	S.E. (gi)	0.25	0.56	2.14	0.27	4.04	0.39	0.05	0.43	0.18	0.06	0.06	0.07
	Range	-3.99 to 3.84	-3.33 to 2.84	-10.46 to 6.97	-2.24 to 2.50	-21.09 to 12.37	-4.23 to 4.67	-0.50 to 0.46	-5.24 to 7.93	-1.94 to 1.87	-3.97 to 8.90	-1.77 to 3.83	-13.32 to 7.29

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

The maximum significant positive *sca* effect was exhibited by hybrid GDM 4 × Dhara (9.69) followed by SKM 9033 × RSK 28 (8.80), GM 3 × LES 45 (8.63), GDM 4 × EC 287711 (7.47) and GM 1 × P. Mustard 21 (6.09). Among these, three hybrids *i.e.*, GDM 4 × Dhara, GDM 4 × EC 287711 and GM 3 × LES 45 depicted positive *sca* effects for number of branches per plant as well as number of silliquae per plant. The hybrids *viz.*, GM 1 × Dhara (0.87), GM 1 × P. Mustard 21 (0.85), GDM 4 × Dhara (0.82) exhibited significant and positive *sca* effect for 1000 seed weight indicating the best specific combiner for developing bold seeded varieties, whereas two hybrids, GDM 4 × P. Mustard 21 (3.74) and GM 1 × LES 45 (3.22) were the best specific combiner for increasing oil content as they had positive and significant *sca* effects. The three hybrids namely GM2 × EC 287711 (-11.20), GM 2 × RSK 28 (-10.34) and LES 45 × RSK 28 (-9.70) showed significant and negative *sca* effect. Therefore, the crosses showing significant *sca* effects are expected to trough off transgressive segregants in segregating generations thus, such crosses can be exploited for the improvement of yield and specific yield contributing characters. Significant positive *sca* effects for seed yield and its important yield component traits have also been reported by Singh *et al*. (2000), Rao and Gulati (2001), Singh *et al.* (2002), Singh *et al.* (2003), Srivastava *et al*. (2009),

Table 3: Estimates of specific combining ability (sca) effects for twelve characters in Indian mustard

Sl. No.	Hybrids	Days to flowering	Days to maturity	Plant height (cm)	No. of branches per plant	No. of siliquae per plant	Seed yield per plant (g)	1000 seed weight (g)	Harvest Index (%)	Oil content (%)	Oleic acid (%)	Lenoleic acid (%)	Erucic acid (%)
1	GM 1 × GM 2	2.35**	2.05	-2.89	2.22*	27.60*	4.01**	-0.54**	2.78	-2.26**	-0.42*	-1.43*	1.52**
2	GM 1 × GM 3	0.43	-0.17	-3.95	4.00**	36.57**	5.59**	-0.59**	2.95*	1.38*	1.80**	3.63**	-3.53**
3	GM 1 × GDM 4	0.68	2.16	1.36	0.45	22.04	0.26	-0.24	-1.03	2.38**	1.63**	1.60**	-2.73**
4	GM 1 × LES 45	-10.15**	-2.42	-11.81	-1.72	-7.36	-2.06	-0.43*	8.42**	3.22**	-8.95**	1.01**	13.26**
5	GM 1 × P. Mustard 21	-1.65	-2.06	-7.97	2.50**	16.9	6.09**	0.85**	5.81**	1.41*	-5.41**	-4.96**	6.53**
6	GM 1 × Dhara	2.32**	-4.42*	-5.35	-0.39	8.79	-0.23	0.87**	4.56**	-1.39*	2.91**	0.57*	-2.56**
7	GM 1 × EC 287711	3.77**	0.86	13.49	-5.76**	-71.00**	-11.83**	0.12	-10.44**	-1.83**	4.39**	2.29**	-7.82**
8	GM 1 × SKM 9033	7.30**	2.80	14.78*	-1.73	-11.33	-3.47*	0.13	-11.55**	1.13	-0.85**	3.49**	-1.17**
9	GM 1 × RSK 28	0.07	1.80	-7.1	-4.91**	-70.16**	-8.27**	-0.06	7.23**	-1.73**	0.59**	-1.37**	1.17**
10	GM 2 × GM 3	1.02	-0.14	-10.77	0.52	31.45*	-0.79	-0.14	8.09**	1.56*	1.84**	7.43**	-5.89**
11	GM 2 × GDM 4	0.93	-0.48	-3.46	0.86	26.05	-0.82	0.30	1.45	-1.68**	-0.30	-0.75**	0.97**
12	GM 2 × LES 45	-6.90**	-3.39	-0.62	-0.97	4.12	-1.08	-0.14	0.23	2.03**	-9.15**	-5.48**	16.95**
13	GM 2 × P. Mustard 21	-0.73	-1.36	-6.66	0.76	16.68	1.11	0.45*	4.95**	1.02	-8.24**	1.26**	10 09**
14	GM 2 × Dhara	0.57	-4.39*	-6.43	-0.83	14.51	1.00	0.45*	5.70**	1.29*	1.92**	-1.53**	-3.05**
15	GM 2 × EC 287711	1.35	5.55**	-3.46	1.16	12.75	2.29	-0.06	2.36	-1.42*	3.71**	9.24**	-11.20**
16	GM 2 × SKM 9033	-1.12	0.83	6.23	0.10	10.71	0.58	0.25	-5.41**	-1.74**	1.36**	0.62**	-1.54**
17	GM 2 × RSK 28	0.66	0.50	7.75	1.60	14.66	3.34*	-0.23	-5 97**	0.52	5.86**	-0.97**	-10.34**
19	GM 3 × GDM 4	1.68	5.97**	5.02	0.26	12.92	-0.62	-0.09	-3.39*	2.16**	1.54**	-1.07**	-0.16
19	GM 3 × LES 45	-0.48	-2.61	-1.41	5.09**	29.09*	8.63**	-0.15	1.39	-0.14	-4.58**	-0.81**	4.05**
20	GM 3 × P. Mustard 21	-9.65**	-3.59	1.36	2.80**	20.59	2.55	0.19	-0.89	0.006	-3.10**	-2.95**	0.96**
21	GM 3 × Dhara	-0.34	5 39**	-0.42	-0.67	22.74	-4.39**	0.52**	-0.14	-0.13	-1.98**	-1.54**	2.25**
22	GM 3 × EC 287711	4.10**	3.33	3.22	-4.86**	-65.45**	-7.93**	0.29	-3.47*	-1.51*	-0.89**	-2.85**	4.60**
23	GM 3 × SKM 9033	7.63**	4.28*	-0.23	-7.42**	-73.08**	-11.88**	0.20	0.75	0.41	1.01**	-0.69*	-0.38
24	GM 3 × RSK 28	0.07	-3.06	4.83	-0.37	-4.74	-1.10	0.14	-3.80*	-1.39*	-0.07	3.31**	-0.38
25	GDM 4 × LES 45	-1.90*	0.39	-4.83	-1.37	-9.95	-2.10	-0.002	2.75	-4.23**	-5 29**	-1.20**	3.15**
26	GDM 4 × P. Mustard 21	5.27**	1.75	-6.27	-1.57	-6.38	-3.23*	0.52**	4.48**	3.74**	1.63**	-4.40**	2.74**
27	GDM 4 × Dhara	-1.43	-4.95*	-1.64	5.86**	38.98**	9.69**	0.82**	2.23	1.18	-4.59**	3.77**	4.00**
28	GDM 4 × EC 287711	-1.98*	-7.34 **	0.99	4.67**	43.45**	7.47**	-0.60**	-0.11	2.73**	-0.01	-1.60**	1.58**
29	GDM 4 × SKM 9033	-0.12	-0.73	3.55	-2.22*	-10.41	-3.41*	-0.62**	-2.89	0.04	0.06	0.02	-0.71**
30	GDM 4 × RSK 28	1.66	2.61	4.21	-7.16**	-34.74*	-7.26**	-0.61**	-3.44*	-0.70	1.45**	1 07**	-3.71**
31	LES 45 × P. Mustard 21	0.10	-0.84	1.10	-2.21*	-25.78	-3.00*	0.35	-1.75	2.14**	2.95**	0.20	-3.95**
32	LES 45 × Dhara	3.41**	0.80	1.79	-0.11	-13.76	-0.97	-0.34	1.00	1.16	3.07**	-0.81**	-5.06**
33	LES 45 × EC 287711	4.18**	-1.25	3.83	1.02	13.99	1.56	0.33	-2.33	0.74	-2.09**	-1.93**	0.76**
34	LES 45 × SKM 9033	8.38**	0.36	2.38	2.53**	22.92	4.04**	0.29	-3.11*	-1.95**	4.30**	-1.84**	-1.66**
35	LES 45 × RSK 28	5.49**	0.69	4.64	0.445	14.63	2.12	0.17	-3.66*	0.09	3.84 *	0.92**	-9.70**
36	P. Mustard 21 × Dhara	2.91**	0.50	-3.04	2.86**	41.18**	4.98**	-0.25	2.73	-0.80	6.14**	3.28**	-5 95**
37	P. Mustard 21 × EC 287711	-5.65**	-1.56	1.19	-0.08	9.62	0.31	0.32	0.06	-0.32	-4.40**	-0.84**	2.93**

38	P. Mustard 21 × SKM 9033	-5.46**	0.05	1.55	-4.60**	-60.35**	-10.60**	0.16	-1.39	-1.23*	0.20	0.48*	-2.47**
39	P. Mustard 21 × RSK 28	3.66**	-7.28**	3.27	2.07*	24.13	4.57**	-0.67**	-1.94	-2.16**	-2.06**	1.54**	-0.34
40	Dhara × EC 287711	2 32**	-1.92	0.68	0.57	17.18	0.27	-0.68**	-3.86*	2.16**	-0.29	-1.73**	1.98**
41	Dhara × SKM 9033	-2.48**	1.36	3.77	-0.66	-27.16	-0.09	-0.20	-2.64	0.43	-1.78**	0.66**	-5.58**
42	Dhara × RSK 28	-1.04	2.69	7.36	-2.64**	-43.45**	-4.23**	0.05	-6.53**	1.57*	-4.95**	-2.12**	9.43**
43	EC 287711 × SKM 9033	0.63	-2.70	-7.66	2.71**	24.45	4.66**	-0.13	6.03**	-0.81	0.25	0.35	-0.94**
44	EC 287711 × RSK 28	-2.26*	-1.03	-2.27	-0.52	-4.88	2.64*	0.48*	2.14	0.17	-0.36	-0.64**	3.11**
45	SKM 9033 × RSK 28	-5.07**	-2.09	-4.18	4.23	39.36**	8.80**	0.09	3.70*	2.03**	-1.50**	-0.24	4.78**
	S.E.(sij)	0.84	1.87	7.21	0.89	13.58	1.30	0.18	1.46	0.61	0.19	0.21	0.23
	Range	-10.15 to 8.38	-7.34 to 5.97	-11.81 to 14.78	-7.42 to 5.86	-73.08 to 43.45	-11.88 to 9.69	-0.68 to 0.87	-11.55 to 8.42	-4.23 to 3.74	-9.15 to 6.14	-5.48 to 9.24	-11.20 to 16.95

**, ** indicate level of significance a! 5 % and 1 %, respectively.*

Table 4: Five top ranking parents with respect to *per se* performance and *gca* effects and the five top ranking hybrids with respect to *per se* performance and their *sca* effects

Characters	Best performing parents	Best general combiners	Best performing hybrids		Hybrids with high *sca* effects		*sca* effects
Days to flowering	GDM 4	GM 2	GM 3 × P. Mustard 21	G × P	GM 1 × LES 45	G × P	-10.15**
	GM 3	GM 3	GM 1 × LES 45	G × P	GM 3 × P. Mustard 21	G × P	-9.65**
	GM 2	GDM 4	GM 2 × LES 45	G × P	GM 2 × LES 45	G × P	-6.90**
	GM 1	GM 1	GM 2 × GM 3	G × G	P. Mustard 21 × EC 287711	P × P	-5.65**
	SKM 9033	RSK 28	GM 2 × GDM 4	G × G	P. Mustard 21 × SKM 9033	P × A	-5.46**
Days to maturity	GM 1	GM 1	GM 1 × Dhara	G × A	GDM 4 × EC 287711	G × P	-7.34**
	GM 2	GM 2	GM 2 × Dhara	G × A	P. Mustard 21 × RSK 28	A × A	-7.28**
	GM 3	GDM 4	GDM 4 × Dhara	G × A	GDM 4 × Dhara	G × A	-4.95*
	GDM 4	Dhara	P. Mustard 21 × RSK 28	A × A	GM 1 × Dhara	G × A	-4.42*
	SKM 9033	—	GDM 4 × EC 287711	G × P	GM 2 × Dhara	G × A	-4.39*
Plant height (cm)	GM 1	GM 1	GM 1 × RSK 28	G × A	GM 1 × LES 45	G × A	-11.81
	RSK 28	GM 2	GM 1 × LES 45	G × A	GM 2 × GM 3	G × A	-10.77
	GDM 4	GDM 4	GM 1 × GM 2	G × G	GM 1 × P. Mustard 21	G × P	-7.97
	SKM 9033	RSK 28	GM 2 × GM 3	G × A	EC 287711 × SKM 9033	A × A	-7.66
	EC 287711	—	GM 1 × GM 3	G × A	GM 2 × P. Mustard 21	G × A	-6.66
No. of branches per plant	GM 1	GM 2	GM 1 × GM 2	G × G	GDM 4 × Dhara	A × P	5.86**
	RSK 28	GM 1	GM 3 × LES 45	A × A	GM 3 × LES 45	A × A	5.09**
	SKM 9033	GDM 4	GM 1 × GM 3	G × A	GDM 4 × EC 287711	A X A	4.67**
	GM 2	LES 45	GDM 4 × EC 287711	A × A	SKM 9033 × RSK 28	A X A	4.23**
	GDM 4	—	GDM 4 × Dhara	A × P	GM 1 × GM 3	G X A	4.00**
No. of siliquae per plant	SKM 9033	GM 2	GDM 4 × EC 287711	A × A	GDM 4 × FC 287711	A × A	43.45**
	RSK 28	LES 45	GM 1 × GM 2	A × G	P. Mustard 21 × Dhara	A × P	41.18**
	GM 1	P. Mustard 21	GM 2 × GDM 4	G × A	SKM 9033 × RSK 28	A × A	39.36**
	LES 45	GDM 4	SKM 9033 × RSK 28	A × A	GDM 4 × Dhara	A × P	38.98**
	EC 287711	GM 1	GM 2 × GM 3	G × P	GM 1 × GM 3	A × P	36.57**

Seed yield per plant (g)	GM 1	GM 2	GM 1 × GM 2	G × G	GDM 4 × Dhara	G × P	9.69**
	GM 3	GM 1	GM 3 × LES 45	G × A	SKM 9033 × RSK 28	P × P	8.80**
	GM 2	GDM 4	GM 1 × GM 3	G × G	GM 3 × LES 45	G × A	8.63**
	SKM 9033	GM 3	GM 1 × P. Mustard 21	G × A	GDM 4 × EC 287711	G × P	7.47**
	GDM 4	—	GDM 4 × EC 287711	G × P	GM 1 × P. Mustard 21	G × A	6.09**
1000 seed weight (g)	GM 2	GM 3	GM 2 × GDM 4	G × A	GM 1 × Dhara	P × P	0.87**
	GM 3	GM 2	GM 2 × GM 3	G × G	GM 1 × P. Mustard 21	P × P	0.85**
	LES 45	LES 45	GM 2 × P. Mustard 21	G × P	GDM 4 × Dhara	A × P	0.82**
	GDM 4	GDM 4	GM 2 × LES 45	G × G	GM 3 × Dhara	G × P	0.52**
	RSK 28	—	GM 3 × LES 45	G × G	GDM 4 × P. Mustard 21	A × P	0.52**
Harvest Index (%)	GM 1	GM 1	GM 1 × RSK 28	G × A	GM 1 × LES 45	G × P	8.42**
	RSK 28	GM 2	GM 1 × GM 2	G × G	GM 2 × GM 3	G × A	8.09**
	GDM 4	GDM 4	GM 1 × LES 45	G × P	GM 1 × RSK 28	G × A	7.23**
	SKM 9033	RSK 28	GM 2 × GM 3	G × A	EC 287711 × SKM 9033	P × P	6.03**
	EC 287711	—	GM 1 × GM 3	G × A	GM 1 × P. Mustard 21	G × P	5.81**
Oil content (%)	SKM 9033	SKM 9033	SKM 9033 × RSK 28	G × G	GDM 4 × P. Mustard 21	G × P	3.74**
	RSK 28	RSK 28	GDM 4 × EC 287711	G × A	GM 1 × LES 45	A × P	3.22**
	EC 287711	GDM 4	GM 1 × SKM 9033	A × G	GDM 4 × EC 287711	G × A	2.73**
	GM 2	EC 287711	GM 1 × GDM 4	A × G	GM 1 × GDM 4	A × G	2.38**
	GM 1	GM 1	GM 3 × GDM 4	A × G	GM 3 × GDM 4	A × G	2.16**
Oleic acid (%)	P. Mustard 21	P. Mustard 21	P. Mustard 21 × Dhara	G × G	P. Mustard 21 × DHARA	G × G	6.14**
	LES 45	LES 45	LES 45 × P. Mustard 21	G × G	GM 2 × RSK 28	P × P	5.86**
	Dhara	Dhara	LES 45 × DHARA	G × G	GM 1 × EC 28771 1	P × P	4.39**
	EC 287711	—	LES 45 × SKM 9033	G × P	LES 45 × SKM 9033	G × P	4.30**
	GDM 4	—	GDM 4 × P. Mustard 21	P × G	LES 45 × RSK 28	G × P	3.84**
Lenoleic acid (%)	P. Mustard 21	P. Mustard 21	P. Mustard 21 × Dhara	G × G	GM 2 × EC 287711	P × A	9.24**
	LES 45	Dhara	GM 2 × EC 287711	P × A	GM2 × GM 3	P × P	7.43**
	Dhara	LES 45	GM 2 × GM 3	P × P	GDM 4 × Dhara	P × G	3.77**
	EC 287711	—	LES 45 × P. Mustard 21	G × G	GM 1 × GM 3	P × P	3.63**
	GDM 4	—	GM 2 × P. Mustard 21	P × G	GM 1 × SKM 9033	P × P	3.49**
Erucic acid (%)	P. Mustard 21	P. Mustard 21	P. Mustard 21 × Dhara	G × G	GM 2 × EC 287711	P × A	-11.20**
	LES 45	LES 45	LES 45 × P. Mustard 21	G × G	GM 2 × RSK 28	P × P	-10.34**
	Dhara	Dhara	LES 45 × Dhara	G × G	LES 45 × RSK 28	G × P	-9.70**
	EC 287711	EC 287711	LES 45 × RSK 28	G × P	GM I × EC 287711	P × A	-7.82**
	GDM 4	—	P. Mustard 21 × SKM 9033	G × P	P. Mustard 21 × Dhara	G × G	-5.95**

Tripathy and Lenka (2010), and Vaghela *et al.* (2011). The best five hybrids selected based on *per se* performance and their *sca* effects are presented in Table 4. A perusal of the data indicated that in general, the best performing hybrid involved atleast one good general combining parent. From these results, it can be pointed out that *per se* performance of the parents and hybrids was also related with *sca* effects of parent and heterotic response of hybrids, respectively. Thus, the potentiality of a strain to be used as a parent in hybridization programme or a cross to be used as a commercial hybrid may be judge by comparing *per se* performance of parents and hybrids along with *gca* of parents and heterotic response of the hybrids. The crosses *viz*., GDM 4 × Dhara, followed by SKM 9033 × RSK 28, GM 3 × LES 45, GDM 4 × EC 287711 and GM 1 × P. Mustard 21 which recorded high and significant *sca* effects for seed yield, resulted from good × poor, poor × poor, good × average, good × poor and good × average general combiners, respectively. A perusal of the data in Table 4 revealed that the crosses having higher estimates of *sca* had resulted from good × poor, good × average, poor × average general combiners. Better performance of hybrids involving average × poor general combiners indicated dominance × dominance (epistasis) type of gene action (Jinks, 1956). Such crosses could be utilized in the production of high yielding homozygous lines (Darrah and Hallauer, 1972).

In the present study, top three crosses which depicted high *sca* effects for seed yield per plant involved at least one good general combiner, indicated additive × dominance type of gene interaction, which could produce desirable transgressive segregants in subsequent generations. Patel *et al.* (2005), Akbar *et al.* (2008), Sharma *et al.* (2008) and Singh *et al.* (2010) have reported the involvement of additive × additive, additive × dominance and epistatic type of gene action in expression of seed yield and other traits in *Brassica*.

CONCLUSION

From the foregoing discussion, it may be concluded that the parent GM 2 was good general combiner for quantitative trait and LES 45 for qualitative traits. The five crosses *viz*., GDM 4 × Dhara, followed by SKM 9033 × RSK 28, GM 3 × LES 45, GDM 4 × EC 287711 and GM 1 × P. Mustard 21 were found to be most promising for seed yield, and other desirable traits, hence these hybrids could be further evaluated and simultaneously advanced in segregating generations to obtain desirable segregants for the development of high yielding genotypes in Indian mustard. It is also clear that high magnitude of non-additive type of gene action for seed yield per plant and some of its important components traits observed in the present study favours hybrid breeding programme.

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