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Research Article

Combining ability and gene action study for grain yield and its attributing traits in Indian mustard

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Abstract
Combining ability and nature of gene interaction that contribute to seed yield and its attributing traits in Indian mustard were investigated using 60 hybrids developed by crossing three females (lines) with twenty males (testers) in a Line x Tester mating system. The results revealed that GCA and SCA ratio (σ^2GCA/σ^2SCA) was less than unity for all the traits except for days to 50 % flowering. This indicated that non-additive components played relatively greater role in the inheritance of all the traits except days to 50 % flowering for which greater role of additive components was found. The estimate of GCA effects indicated that the parents GM-2, NRCM-120, PAB-9511 and IC-261670 were identified as good general combiners indicating their ability in transmitting additive genes in the desirable direction to their progenies. The hybrids *viz.,* GM-2 x PYM-7 (10.81), GM-3 x NUDH-45-1 (10.70) and GM-3 x PAB-9511 (8.36) were found to be the best specific crosses for seed yield per plant. Among these hybrids, GM-2 x PTM-7 was also recorded significant *sca* effects in desired direction for number of primary branches per plant, number of secondary branches per plant and number of siliquae per plant, while GM-3 x NUDH-45-1 also exhibited significant *sca* effects for number of primary branches per plant, number of secondary branches per plant, number of siliquae per plant, siliquae length and oil content. Therefore, these hybrids can be further exploited for selection of transgressive segregants.

Key words
General combining ability (GCA), seed yield, specific combining ability (SCA), Indian mustard, yield components

Introduction

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. Among the major oilseed producing countries India contributes about 7% at the global level. India, with an area of 7.20 million hectares, 7.88 million metric tonnes production and 1094 kg/ha productivity, ranks second in area and third in production in rapeseed-mustard scenario of the world in 2014-2015 (Anonymous, 2015). To fulfill requirement of ever-increasing population of India, there is a dire need of improving genotypes for better seed yield potential per unit area basis. This could be achieved by exploring the maximum genetic potential from the available germplasm of Indian mustard. Breeders should concentrate on development of productive mustard varieties by crossing good general combining lines for seed yield and selecting transgressive segregants from the resulting hybrids.

The success of any breeding programme largely depends upon the choice of parents and the breeding procedure adopted. Combining ability analysis was carried out in the present investigation to obtain useful information for selection of better parents and crosses for their future use in breeding program. In addition to this, information regarding nature and magnitude of gene action could also be obtained, which is useful in deciding breeding methodology aiming to exploit fixable (additive) and non-fixable (non-additive) genetic variances.

Materials and methods

The experimental material comprised of three females, twenty male parents (Table 1) and their 60 F_1S developed by crossing three females (lines) with twenty males (testers) in a Line x Tester mating system. The seeds of 60 F_1 hybrids and 23 parents were produced by hand emasculation-hand pollination and selfing, respectively during *rabi* 2013-14. These 60 F_1 hybrids along with 23 parents were evaluated in randomized block design with three replications during *rabi* 2014-15 at Anand Agricultural University, Anand. This site located at 220 35' North Latitude and 720 55' East longitude at an elevation of 45.1 m above mean sea level. Inter and intra row spacing was kept 40 and 15 cm, respectively. All the recommended package of practices was adopted to raise a good crop.

For recording observations, 5 competitive plants were randomly selected and tagged from each treatment in each replication and the mean value per plant was computed for various yield and its attributing traits *viz.,* plant height (cm), number of primary branches, number of secondary branches, effective length of main branch (cm), number of siliquae on main spike, number of siliquae per plant, siliqua length (cm), number of seeds per siliqua, seed yield per plant (g), thousand seed weight (g), oil content (%) and protein content (%). The phenological characters *viz.,* days to flowering and days to maturity were recorded on plot basis. Analysis of variance and estimation of combining ability effects were made as per Kempthorne (1957).

Results and discussion

The analysis of variance for combining ability for different characters has been presented in Table 2. The variation present in the hybrids was partitioned into portions attributable to females, males and female x male and error component. A comparison of variances due to females and males indicated that females showed higher magnitude of variability for days to 50 % flowering, days to maturity, plant height, no. of primary branches per plant, length of main branch, no. of siliquae on main branch, no. of siliquae per plant, length of siliquae, no. of seeds per siliquae and seed yield per plant. This indicated that the contribution of females for these traits towards GCA was greater. Male showed higher magnitude of variability for no. of secondary branches per plant, 1000 seed weight, oil content and protein content. This indicated that the contribution of male for these traits towards GCA was greater.

The magnitude of GCA and SCA variances revealed that the SCA variances were higher than their respective GCA variances for all the characters except for days to 50% flowering. The GCA and SCA ratio (σ^2GCA/σ^2SCA) was less than unity for all the traits except for days to 50% flowering. This suggested relatively greater role of non-additive genetic variance in the inheritance of all the traits except days to 50 % flowering for which greater role of additive gene effect was found.

A perusal of mean values of different parents and their cross combinations for various traits (Table 3) revealed that most of the hybrids were found superior than male parent but less number of hybrids found superior than female parent with respect to seed yield and various component characters. Among parents, GM-3 (28.37 g), GM-2 (26.07 g), NPJ-95 (25.79 g) and PBR-357 (23.61 g) exhibited higher per se performance for seed yield per plant and their contributing traits. Male parents *viz.*, RH-8813 (35.01%), B-351 (34.56%) and NUDH-45-1 (34.47%) exhibited high oil content. Parents desirable for earliness were GM-1, NPJ-90 and NPJ-95.Among the hybrids GM-2 x PYM-7 exhibited maximum seed yield per plant (34.52 g) followed by GM-3 x PAB-9511 (34.44 g) and GM-3 x NUDH-45-1 (31.91 g).

High *gca* effects are related to additive gene effects or additive × additive effects (Griffing, 1956), which represent the fixable genetic component of variance. It may therefore, be suggested that the parents with high *gca* effects may be extensively used in hybridization programme for the improvement of particular traits. General combining ability effects of the parents (Table 4) revealed that none of the parents was found to be good general combiner for all the characters. An overall appraisal of GCA effects revealed that parents GM-2, NRCM-120, PAB-9511 and IC-261670 were good general combiners for seed yield per plant and some of its components. The line GM-2 was found to be a good general combiner for seed yield and all the yield attributing characters except length of main branch, no. of siliquae on main branch and 1000 seed weight. Among the male parents, NRCM-120 was a good general combiner for seed yield per plant, days to 50% flowering, days to maturity, plant height, number of secondary branches per plant, no. of siliquae per plant and no. of seeds per siliquae, which may be utilized in crossing programme to generate the genetic variability for effective selection to develop high yielding varieties as well as earliness in Indian mustard. While the male parents PAB-9511 and IC-261670 was a good general combiner for seed yield per plant, number of primary branches per plant, number of secondary branches per plant and no. of siliquae per plant. For quality components, lines GM-2 and GM-1 as well as GM-3 were found to be good general combiners for oil content and protein content, respectively. While male parents RH-8813, SKM-9588 and DIR 747 were found to be good general combiners for oil content and protein content

The parents NRCM-120, PAB-9511 and IC-261670 were good general combiner for seed yield and some of its components, but their *per se* performance was poor. While, GM-3, PBR-357 and RSK-29 were average to poor general combiner for most of the characters, even though their *per se* performance was good.

Therefore, parents GM-2, NRCM-120, PAB-9511 and IC-261670 can be considered as a good source of favorable genes for increasing seed yield along with other yield attributes. It is evident from these results that high *gca* effects for seed yield per plant in these parents were mainly due to important yield contributing characters mentioned above. Therefore, it would be worthwhile to use the above parental lines (GM-2, NRCM-120, PAB-9511 and IC-261670) in the hybridization programme for improvement of Indian mustard.

The SCA is the deviation from the performance predicted on the basis of general combining ability (Allard, 1960). Normally SCA effects would not contribute appreciably in the improvement of self-pollinated crops except where exploitation of heterosis is feasible. However, in the production of homozygous lines, breeder's interest usually rests upon transgressive segregation shown by the crosses. The estimates of specific combining ability effects revealed that as many as twenty cross combinations exhibited significant and positive *sca* effects for seed yield per plant. The maximum significant positive *sca* effect was exhibited by hybrid GM-2 x PYM-7 (10.81) followed by GM-3 x NUDH-45-1 (10.70) and GM-3 x PAB-9511 (8.36) and thus were good hybrid combinations, contributing towards higher seed yield (Table 5). The cross combination GM-2 x PTM-7 (Good x Good) also recorded significant *sca* effects in desired direction for number of primary branches per plant, number of secondary branches per plant and number of siliquae per plant. The cross GM-3 x NUDH-45-1 (Average x Good) exhibited significant *sca* effects for seed yield per plant as well as number of primary branches per plant, number of secondary branches per plant, number of siliquae per plant, siliquae length and oil content. While the cross GM-3 x PAB-9511 (Average x Good) exhibited significant *sca* effects for seed yield per plant, days to 50 % flowering, days to maturity, number of secondary branches per plant, no. of siliquae per plant, length of siliquae, no. of seeds per siliquae and protein content. In the present study, top three crosses which exhibited high *sca* effects for yield per plant involved at least one good general combiner, indicating additive x dominance type of gene interaction, which could produce desirable transgressive segregants in subsequent generations. Therefore, these three hybrids can be further exploited for selection of transgressive segregants.

The GCA and SCA ratio (σ^2GCA/ σ^2SCA) was less than unity for all the traits except for days to 50% flowering. This indicated that non-additive components played relatively greater role in the inheritance of all the traits except days to 50 % flowering for which greater role of additive components was found. Therefore, mass selection or pedigree selection might be fruitful in early segregating generations for the improvement of the traits controlled by additive genes action. While selection must be delayed to late segregating generations (F_6) as in bulk if necessary for the improvement of the traits controlled by non-additive genes action. The results are in conformity with those obtained earlier by Patel *et al.* (2005) Macwana (2008), Singh *et al.* (2010), Nasrin *et al.* (2011), Yadava *et al.* (2012), Kumar *et al.* (2013), Saeed *et al.* (2013), Dholu *et al.* (2014) and Niranjana *et al*. (2014).

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Table 1. List of parental genotypes of proposed study

S. No.	Female Parents	Special attributes
1.	GM-1	Medium height, early maturing and medium seed size
2.	GM-2	Large seeded and high yielding
3.	GM-3	Early maturing, large seeded and high yielding
	Male Parents	
1.	PYM-7	Small siliquae length, small seeded as well as stem rot resistance
2.	NUDH-45-1	More plant height (Tall), more branches and high yielding
3.	PRN-393	Tall and small seeded
4.	B-351	Small seeded and more branching ability
5.	IC-261670	Tall and long main branch
6.	NPJ-95	Early maturity, more branches and high yielding
7.	SW-91-1	Small seeded
8.	RH-8813	Small main branch, few siliquae on main branch and medium oil content
9.	SKM-0157	Early maturing and less branching
10.	SKM-9588	Long main branch, more branches, long siliquae and high yielding
11.	SKM-9825	Medium height, less branches and small seeded
12.	RSK-29	Late maturing, long main branch and high yielding
13.	PBR-357	Tall, long siliquae, large seeded and high yielding
14.	AA-52	Tall, long main branch and large seeded
15.	RRCM-74	Long siliquae and less branching
16.	PAB-9511	Late maturing and low oil content
17.	IC-131819	Medium height, more branches, long main branch and high yielding
18.	NRCM-120	Low plant height and early maturing
19.	NPJ-90	Early maturing, low height, long siliquae and small seeded
20.	DIR-747	Late maturing

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Table 2. Analysis of variance for combining ability of different characters in Indian mustard

Sources of variation	d.f.	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of primary branches per plant	No. of secondary branches per plant	Length of main branch (cm)	No. of siliquae on main branch	No. of siliquae per plant	Length of siliquae (cm)	No. of seeds per siliquae	Seed yield per plant (g)	1000 seed weight (g)	Oil content (%)	Protein content (%)
Replication	2	0.93	3.96	59.73	5.20**	56.65**	40.43	15.24	758.04	0.65**	3.83**	2.36	0.31**	7.94**	1.20*
Line (L)	2	287.03**	367.90**	787.20*	4.99	13.13	276.08	55.62	59050.93*	2.53**	20.52**	396.60**	0.27	6.75	3.51
Tester effect (T)	19	59.60**	64.67**	609.66**	2.97	19.52	151.07	43.69	12097.82	0.73	3.25	69.12	0.41	8.01	4.65
L x T	38	16.20**	21.69**	239.97**	1.74**	19.87**	107.95**	51.27**	12439.64**	0.47**	2.59**	69.72**	0.34**	6.82**	4.36**
Error	118	2.75	5.52	86.05	0.19	1.42	14.24	7.12	802.74	0.11	0.75	3.79	0.028	0.45	0.34
Estimates of variance components															
Lines	2	4.51**	5.77**	9.12*	0.05	-0.11	2.80	0.07	776.85*	0.03**	0.30**	5.45**	-0.0011	-0.0012	-0.014
Testers	19	4.82**	4.78**	41.08**	0.14	-0.04	4.79	-0.84	-37.98	0.03	0.07	-0.07	0.0087	0.13	0.032
GCA		4.79**	4.87**	38.04**	0.13	-0.046	4.60	-0.75	39.62	0.03**	0.092**	0.46	0.0077	0.12	0.027
SCA	39	4.48**	5.39**	51.30**	0.52**	6.15**	31.24**	14.72**	3878.97*	0.12**	0.61**	21.98**	0.10**	2.12**	1.34**
GCA/SCA		1.07	0.90	0.74	0.25	-0.01	0.15	-0.05	0.01	0.25	0.15	0.02	0.08	0.06	0.02

*,** Significant at 5 and 1 per cent levels, respectively.

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Table 3. Mean values of parents and hybrids for various characters in Indian mustard

Treatments	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of primary branches per plant	No. of secondary branches per plant	Length of main branch (cm)	No. of siliquae on main branch	No. of siliquae per plant	Length of siliquae (cm)	No. of seeds per siliquae	Seed yield per plant (g)	1000 seed weight (g)	Oil content (%)	Protein content (%)
FEMALE														
GM-1	***45.33***	***105.67***	***160.40***	***6.13***	***17.07***	***71.27***	***50.60***	***414.73***	***4.51***	***13.73***	***22.28***	***4.61***	***31.11***	***22.10***
GM-2	**50.33**	110.33	**177.87**	**6.93**	**22.73**	76.87	52.27	462.73	4.97	**14.53**	26.07	4.85	31.68	**24.30**
GM-3	48.67	**112.33**	175.07	6.73	21.13	**78.60**	**53.93**	**495.33**	**5.31**	13.93	**28.37**	**5.09**	**32.40**	24.06
MALE														
PYM-7	55.33	115.33	182.67	6.13	13.27	56.87	48.67	374.73	***4.19***	13.73	14.32	***3.10***	***29.08***	24.41
NUDH-45-1	50.67	116.33	193.67	7.13	**17.07**	64.67	44.67	**466.73**	4.95	15.27	21.89	3.42	34.47	**26.45**
PRN-393	52.33	113.67	**194.67**	**7.53**	13.93	60.07	44.93	392.40	4.81	12.60	17.08	3.85	32.31	23.94
B-351	52.67	112.67	176.67	6.13	16.13	64.67	46.60	308.53	5.05	13.67	12.85	3.38	34.56	25.44
IC-261670	54.00	114.00	191.93	6.53	14.93	73.47	50.87	371.67	4.73	12.20	16.39	4.02	30.50	24.83
NPJ-95	46.67	106.67	161.27	6.13	16.27	66.07	***40.40***	373.53	5.55	15.73	**25.79**	4.87	31.71	23.79
SW-91-1	53.67	113.67	183.27	6.13	13.53	62.67	43.87	346.73	4.35	13.07	16.32	4.01	32.93	22.62
RH-8813	56.67	116.67	178.27	6.33	15.47	56.67	42.13	276.13	4.93	14.73	13.93	3.81	**35.01**	22.59
SKM-0157	51.67	111.67	176.07	6.53	***12.27***	60.47	48.73	***223.33***	4.95	12.27	13.00	5.29	31.02	24.02
SKM-9588	52.67	112.67	186.07	6.53	15.73	74.07	49.93	354.33	5.63	13.93	20.34	4.55	33.60	***22.55***
SKM-9825	54.33	114.33	182.07	6.53	13.73	60.87	45.00	273.87	4.60	12.33	12.73	4.19	31.50	24.33
RSK-29	55.33	118.33	178.67	5.53	13.93	**78.87**	54.67	391.73	5.25	14.47	22.53	4.41	32.19	24.05
PBR-357	56.67	119.33	189.47	5.93	14.80	73.47	51.27	353.93	**6.13**	13.13	23.61	**5.66**	30.71	23.00
AA-52	55.33	115.00	185.07	5.73	13.87	78.47	**57.47**	353.80	4.83	***11.87***	19.10	5.06	32.97	22.85
RRCM-74	56.33	116.33	164.47	***4.93***	12.87	70.87	53.33	311.60	5.55	14.00	19.37	4.92	32.40	23.73
PAB-9511	58.33	119.33	182.87	5.33	14.27	66.07	48.93	312.53	4.63	13.13	13.77	3.73	29.25	24.73
IC-131819	52.33	117.00	160.27	5.13	14.27	75.07	46.47	308.00	5.23	14.67	20.09	4.92	32.29	25.03
NRCM-120	49.33	109.33	***147.67***	5.53	13.60	65.67	44.27	255.80	5.45	**15.73**	14.63	4.03	31.78	22.63
NPJ-90	***46.33***	***105.67***	152.27	5.73	12.67	***55.67***	43.73	255.00	5.99	14.73	***12.14***	3.56	33.20	24.67
DIR-747	**58.67**	**122.67**	182.27	5.33	13.53	67.47	52.33	295.07	5.13	12.40	15.66	4.75	31.38	25.80
HYBRIDS														
GM-1 × PYM-7	49.67	108.33	183.27	6.73	19.67	72.33	46.00	360.53	4.53	13.87	14.09	3.32	33.15	23.33
GM-1 × NUDH-45-1	46.33	107.33	183.20	7.00	18.00	71.93	46.53	344.33	5.19	13.73	13.60	3.38	32.30	24.00
GM-1 × PRN-393	49.00	***105.67***	176.47	6.53	15.80	73.87	44.33	283.13	5.51	13.87	12.94	3.87	30.41	22.58
GM-1 × B-351	48.33	109.33	171.27	7.33	20.00	80.27	50.40	412.73	5.27	13.20	16.08	3.47	34.12	23.04
GM-1 × IC-261670	50.67	109.67	186.67	6.13	16.13	71.47	48.00	345.33	5.91	13.53	17.42	4.38	30.90	24.80
GM-1 × NPJ-95	45.67	106.00	167.47	6.53	13.80	73.07	46.87	320.33	5.71	14.20	14.97	3.87	29.78	22.11
GM-1 × SW-91-1	49.67	108.67	184.27	7.13	12.20	75.67	48.20	298.60	5.11	13.33	12.56	3.73	28.49	21.14
GM-1 × RH-8813	48.33	108.33	175.87	6.53	17.40	74.27	45.67	405.33	5.75	13.67	17.54	3.74	33.39	24.81

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Table 3. Contd.,

Treatments	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of primary branches per plant	No. of secondary branches per plant	Length of main branch (cm)	No. of siliquae on main branch	No. of siliquae per plant	Length of siliquae (cm)	No. of seeds per siliquae	Seed yield per plant (g)	1000 seed weight (g)	Oil content (%)	Protein content (%)
Hybrids														
GM-1 × SKM-0157	47.33	106.67	177.47	5.53	15.67	72.27	45.93	343.73	5.35	15.27	16.75	3.76	33.00	24.84
GM-1 × SKM-9588	50.00	107.33	195.47	7.73	16.27	62.67	44.40	298.47	5.25	14.33	15.20	3.91	31.91	23.75
GM-1 × SKM-9825	48.00	108.00	198.07	6.93	15.07	68.73	50.33	387.67	5.21	12.93	16.74	3.93	33.32	22.00
GM-1 × RSK-29	48.67	108.67	191.87	6.73	16.67	77.87	51.67	415.73	5.41	**16.27**	20.54	3.58	32.24	23.96
GM-1 × PBR-357	49.67	110.00	185.87	6.73	16.40	75.27	49.80	403.73	5.27	15.33	20.33	3.87	29.93	24.71
GM-1 × AA-52	53.00	115.67	179.87	6.13	14.60	67.20	53.47	423.80	4.67	***11.27***	16.52	4.05	32.85	23.89
GM-1 × RRCM-74	47.67	111.00	167.07	5.53	14.87	82.27	45.33	***255.93***	5.39	13.33	12.38	4.13	28.48	25.02
GM-1 × PAB-9511	53.33	113.33	191.47	8.33	17.93	65.07	51.47	485.93	5.07	12.80	20.21	3.81	31.39	21.78
GM-1 × IC-131819	50.33	110.33	181.67	6.13	15.13	76.40	47.00	411.87	5.45	14.07	21.94	4.43	33.90	25.44
GM-1 × NRCM-120	46.00	106.33	161.27	5.33	17.60	76.67	49.67	436.13	5.21	15.67	24.75	4.27	31.24	23.20
GM-1 × NPJ-90	***45.00***	**105.67**	168.67	5.93	18.20	79.47	51.40	414.13	5.47	13.07	15.30	3.33	33.04	22.34
GM-1 × DIR-747	56.33	116.33	197.87	5.13	15.60	**91.07**	56.07	408.13	***3.99***	13.07	16.14	3.56	32.51	24.69
GM-2 × PYM-7	54.67	114.00	189.67	7.93	**23.73**	***61.07***	47.40	**565.13**	4.89	13.80	**34.52**	3.48	32.65	21.01
GM-2 × NUDH-45-1	53.67	113.67	196.07	5.73	12.80	79.27	**58.40**	353.73	5.05	14.93	18.78	4.11	31.15	23.76
GM-2 × PRN-393	49.67	109.67	197.47	7.53	18.00	78.27	54.27	486.33	5.63	14.73	23.69	3.89	33.91	22.31
GM-2 × B-351	55.67	115.67	187.67	6.53	15.20	62.27	47.73	427.93	4.87	14.13	20.17	3.92	32.42	23.55
GM-2 × IC-261670	49.33	109.33	184.67	**8.73**	23.00	67.67	48.40	515.93	5.15	13.93	31.12	3.54	31.85	24.54
GM-2 × NPJ-95	48.67	109.00	174.47	7.33	19.80	77.07	44.40	402.93	**6.09**	15.33	17.29	***3.29***	29.34	24.92
GM-2 × SW-91-1	51.67	111.67	171.07	7.33	18.33	65.27	***41.87***	415.73	5.31	15.33	19.75	3.66	31.44	25.35
GM-2 × RH-8813	55.67	117.33	207.87	6.93	16.93	78.53	54.40	478.73	5.89	13.60	20.41	3.68	32.81	22.85
GM-2 × SKM-0157	54.00	115.67	190.27	7.33	17.00	64.47	50.07	469.60	5.29	14.87	24.15	4.08	32.80	23.28
GM-2 × SKM-9588	54.33	114.67	199.87	8.13	15.47	79.87	57.00	419.53	5.73	14.47	17.25	3.35	33.53	**25.59**
GM-2 × SKM-9825	53.33	113.33	195.67	7.67	16.60	65.47	43.67	400.33	5.83	14.67	21.93	4.41	32.10	22.20
GM-2 × RSK-29	56.33	117.33	**209.47**	5.93	14.27	80.60	54.87	410.93	5.27	15.13	22.74	4.31	31.64	23.09
GM-2 × PBR-357	50.00	109.33	188.67	5.53	13.33	68.00	48.93	343.53	5.23	13.67	16.15	4.05	30.77	23.86
GM-2 × AA-52	47.67	107.67	176.07	6.53	13.93	69.47	44.40	346.20	6.01	14.20	14.76	3.54	30.18	21.67
GM-2 × RRCM-74	50.33	110.33	183.27	7.13	21.40	79.47	55.20	490.47	5.87	13.47	25.38	4.53	32.61	24.29
GM-2 × PAB-9511	58.33	118.33	196.47	7.13	15.80	73.53	57.07	454.73	5.25	14.87	24.26	4.23	31.82	22.20
GM-2 × IC-131819	54.67	115.33	187.27	6.73	17.20	65.33	44.73	383.67	5.97	13.27	18.26	4.23	33.35	***20.45***
GM-2 × NRCM-120	48.00	106.00	171.67	6.73	19.60	71.47	44.67	434.53	5.89	14.93	21.17	3.85	31.67	22.53
GM-2 × NPJ-90	47.33	108.33	***149.87***	8.53	22.13	66.07	43.47	457.73	5.25	15.40	22.50	3.76	33.25	22.74
GM-2 × DIR-747	**59.33**	**119.33**	182.87	5.33	12.87	69.53	51.53	450.73	5.11	13.67	24.25	4.65	32.22	22.94
GM-3 × PYM-7	56.00	114.00	170.67	6.13	13.40	63.87	51.13	392.93	4.31	11.13	14.48	3.90	30.51	25.12

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Table 3. Contd.,

Treatments	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of primary branches per plant	No. of secondary branches per plant	Length of main branch (cm)	No. of siliquae on main branch	No. of siliquae per plant	Length of siliquae (cm)	No. of seeds per siliquae	Seed yield per plant (g)	1000 seed weight (g)	Oil content (%)	Protein content (%)
Hybrids														
GM-3 × NUDH-45-1	51.67	116.33	192.67	7.53	20.07	66.73	55.07	506.80	5.35	13.13	31.91	4.01	32.87	23.30
GM-3 × PRN-393	56.00	116.00	192.27	7.33	15.80	61.47	50.47	401.73	5.91	13.40	18.40	4.03	32.67	24.23
GM-3 × B-351	53.67	114.67	185.87	6.33	19.40	66.07	47.40	418.07	5.21	14.00	17.22	3.46	31.30	23.70
GM-3 × IC-261670	56.67	116.67	190.87	6.33	14.13	65.67	52.87	409.33	**6.09**	13.40	17.51	3.76	31.19	23.68
GM-3 × NPJ-95	45.33	107.33	172.87	***4.93***	13.87	89.47	55.73	280.33	4.45	15.27	16.82	4.65	33.52	24.83
GM-3 × SW-91-1	49.67	108.67	193.87	6.93	15.07	72.07	50.40	338.53	4.85	11.40	13.14	4.02	31.38	24.01
GM-3 × RH-8813	52.33	114.00	185.47	6.13	14.40	72.87	53.00	287.53	5.09	13.33	13.28	4.09	32.75	23.77
GM-3 × SKM-0157	53.67	113.67	180.47	5.33	***10.33***	64.07	50.67	265.73	5.25	12.53	***11.71***	4.15	31.03	21.90
GM-3 × SKM-9588	51.67	111.67	189.07	6.53	15.20	77.67	49.53	454.33	4.91	13.47	18.91	3.65	31.97	24.02
GM-3 × SKM-9825	50.00	109.67	195.67	7.73	20.80	66.47	44.33	459.73	4.57	12.07	16.95	3.60	31.02	22.75
GM-3 × RSK-29	55.33	116.00	193.53	6.53	18.07	76.07	50.27	360.13	4.27	12.80	14.71	3.76	31.10	24.29
GM-3 × PBR-357	56.67	116.67	183.27	6.13	15.33	70.67	49.93	359.33	5.39	13.13	16.33	**5.39**	29.28	24.91
GM-3 × AA-52	54.33	114.67	184.67	6.53	15.87	70.07	53.93	432.13	5.01	12.20	15.77	3.52	31.33	21.36
GM-3 × RRCM-74	54.00	117.00	187.07	6.53	16.13	71.07	44.33	375.33	5.15	14.27	21.00	4.63	**34.95**	23.79
GM-3 × PAB-9511	55.67	115.67	203.67	7.93	23.33	68.27	50.87	541.33	5.27	14.40	34.44	3.70	27.59	23.69
GM-3 × IC-131819	55.00	115.00	191.67	6.13	18.53	70.07	47.60	456.73	5.17	13.87	25.38	4.01	31.32	22.19
GM-3 × NRCM-120	52.33	112.33	190.87	7.13	18.60	66.07	53.60	450.13	4.97	14.13	21.75	3.80	***27.80***	23.28
GM-3 × NPJ-90	47.33	107.33	187.87	7.53	18.40	73.87	47.27	360.73	5.11	13.33	16.32	3.76	31.91	22.51
GM-3 × DIR-747	56.33	119.67	186.47	5.93	15.13	74.27	52.60	469.87	5.07	13.73	24.49	4.23	32.68	24.29
Parent mean	52.77	113.87	176.65	6.12	15.00	67.95	48.61	347.12	5.08	13.80	18.45	4.36	32.09	24.04
Females	48.11	109.44	171.11	6.60	20.31	76.91	53.27	461.40	4.93	14.56	26.24	4.89	31.73	23.82
Males	53.47	114.53	177.48	6.04	14.21	66.61	47.91	329.97	5.10	13.68	17.28	4.28	32.14	24.07
Hybrid mean	51.66	111.93	185.40	6.71	16.62	71.95	49.60	403.08	5.26	13.84	19.24	3.90	31.77	23.44
General mean	51.96	112.47	182.98	6.55	16.17	70.84	49.33	387.57	5.21	13.83	19.02	4.02	31.86	23.60
C.V. %	3.15	2.03	5.12	6.21	7.09	5.21	5.34	7.19	6.10	6.15	10.44	4.24	2.09	2.45
S. Em.	0.94	1.32	5.41	0.23	0.66	2.13	1.52	16.09	0.18	0.49	1.15	0.10	0.38	0.33
C.D. @ 5 %	2.62	3.66	14.99	0.65	1.84	5.91	4.22	44.60	0.51	1.36	3.18	0.27	1.06	0.93

Bold letter- Highest value
Bold and italic letter- lowest value

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Table 4. Estimates of general combining ability (*gca*) effects of parents for various characters in Indian mustard

Parents	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of primary branches per plant	No. of secondary branches per plant	Length of main branch (cm)	No. of siliquae on main branch	No. of siliquae per plant	Siliquae length (cm)	No. of seeds per siliquae	Seed yield per plant	1000 seed weight (g)	Oil content (%)	Protein content (%)
FEMALE														
GM-1	**_-2.51**_**	**_-2.79**_**	**_-4.15**_**	**_-0.20**_**	**_-0.42**_**	**2.44****	**_-0.97**_**	**_-30.30**_**	-0.03	0.003	**_-2.45**_**	**_-0.09**_**	0.05	**0.14****
GM-2	0.98**	0.87**	1.61	**0.33****	**0.60****	-0.82*	0.02	**32.34****	**0.22****	**0.58****	**2.68****	0.01	**0.31****	**_-0.28**_**
GM-3	**1.53****	**1.92****	**2.54****	-0.13**	-0.18	**_-1.61**_**	**0.95****	-2.04	**_-0.19**_**	**_-0.59**_**	-0.22	**0.09****	**_-0.36**_**	**0.14****
S. E.± (lines)	0.15	0.21	0.83	0.04	0.11	0.34	0.24	2.54	0.03	0.08	0.17	0.02	0.06	0.05
MALE														
PYM-7	1.79**	0.18	-4.20	0.22	2.16**	**_-6.20**_**	-1.42	36.45**	**_-0.68**_**	-0.90**	1.78**	**_-0.35**_**	0.34	-0.28
NUDH-45-1	-1.10*	0.52	5.24*	0.05	0.18	0.69	3.73**	-1.46	-0.06	0.10	2.18**	-0.09	0.34	0.25
PRN-393	-0.10	-1.48*	3.33	0.42**	-0.24	-0.75	0.09	-12.68	0.42**	0.16	-0.91	0.01	0.56**	-0.40*
B-351	0.90*	1.29*	-3.80	0.02	1.43**	-2.42*	-1.09	16.50*	-0.14	-0.06	-1.43**	-0.30**	0.85**	-0.01
IC-261670	0.57	-0.04	2.00	0.36**	0.98**	-3.69**	0.16	20.45**	**0.46****	-0.21	2.77**	-0.02	-0.45*	0.90**
NPJ-95	**_-5.10**_**	-4.48**	-13.80**	-0.44**	-0.95**	**7.91****	-0.60	**_-68.55**_**	0.16	**1.10****	-2.89**	0.02	-0.89**	0.51**
SW-91-1	-1.32**	-2.26**	-2.34	0.42**	-1.57**	-0.95	-2.78**	-52.13**	-0.17	-0.48*	**_-4.10**_**	-0.12*	-1.33**	0.06
RH-8813	0.46	1.29*	4.33	-0.18	-0.53	3.27**	1.42	-12.55	0.32**	-0.30	-2.18**	-0.08	**1.22****	0.37*
SKM-0157	0.011	0.07	-2.67	-0.64**	-2.44**	-5.02**	-0.71	-43.39**	0.04	0.39	-1.72**	0.08	0.51**	-0.10
SKM-9588	0.34	-0.71	9.40**	0.76**	-1.13**	1.45	0.71	-12.30	0.04	0.25	-2.13**	-0.28**	0.70**	1.02**
SKM-9825	-1.21**	-1.59*	11.06**	0.73**	0.72*	-5.07**	**_-3.49**_**	12.83	-0.06	-0.61*	-0.71	0.06	0.38*	-1.12**
RSK-29	1.79**	2.07**	**12.89****	-0.31**	-0.44	6.22**	2.67**	-7.48	-0.28**	0.90**	0.08	-0.03	-0.11	0.34*
PBR-357	0.46	0.07	0.53	-0.58**	-1.75**	-0.64	-0.04	-34.21**	0.04	0.21	-1.65**	**0.52****	**_-1.77**_**	**1.06****
AA-52	0.011	0.74	-5.20*	-0.31**	-1.97**	-3.04**	1.00	-2.37	-0.034	**_-1.28**_**	-3.57**	-0.22**	-0.31	**_-1.13**_**
RRCM-74	-0.99	0.85	-6.27*	-0.31**	0.70*	5.65**	-1.31	-29.17**	0.21*	-0.15	0.34	0.51**	0.25	0.93**
PAB-9511	4.12**	3.85**	11.80**	**1.09****	2.25**	-3.00**	3.53**	**90.92****	-0.06	0.19	**7.05****	0.00	-1.50**	-0.88**
IC-131819	1.68**	1.63*	1.46	-0.38**	0.18	-1.35	-3.16**	14.34	0.27**	-0.10	2.61**	0.30**	1.09**	-0.74**
NRCM-120	-2.88**	-3.71**	-10.80**	-0.31**	1.83**	-0.55	-0.29	37.19**	0.10	1.07**	3.31**	0.05	-1.53**	-0.43**
NPJ-90	**_-5.10**_**	**_-4.82**_**	**_-16.60**_**	0.62**	**2.81****	1.18	-2.22**	7.79	0.02	0.10	-1.21*	-0.30**	0.96**	-0.91**
DIR-747	**5.68****	**6.52****	3.66	**_-1.24**_**	**_-2.24**_**	6.33**	**3.80****	39.83**	-0.54**	-0.35	2.38**	0.23**	0.71**	0.54**
S. E. ± (testers)	0.46	0.65	2.56	0.12	0.33	1.04	0.74	7.83	0.09	0.24	0.54	0.05	0.18	0.16
Range	***-5.10*** **to 5.68**	***-4.82*** **to 6.52**	***-16.60*** **to 12.89**	***-1.24*** **to 1.09**	***-2.24*** **to 2.81**	***-6.20*** **to 7.91**	***-3.49*** **to 3.80**	***-68.55*** **to 90.92**	***-0.68*** **to 0.46**	***-1.28*** **to 1.10**	***-4.10*** **to 7.05**	***-0.35*** **to 0.52**	***-1.77*** **to 1.22**	***-1.13*** **to 1.06**

*, ** Significant at 5 % and 1 % levels, respectively.
Bold letter, bold and italic letter indicate: highest positive and highest negative GCA effect value, respectively.

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Table 5. Three most promising crosses (SCA effect) for seed yield per plant along with *per se* performance and their SCA effects for component characters in Indian mustard

S. No.	Crosses	GCA of parent	Mean seed yield per plant (g)	SCA effect for seed yield per plant (%)	Also desirable SCA effect for other traits
1	GM-2 x PYM-7	G x G	34.52	10.81**	Number of primary branches per plant, number of secondary branches per plant and number of siliquae per plant.
2	GM-3 x NUDH-45-1	A x G	31.91	10.70**	Number of primary branches per plant, number of secondary branches per plant, number of siliquae per plant, siliquae length and oil content.
3	GM-3 x PAB-9511	A x G	34.44	8.36**	Days to 50 % flowering, days to maturity, number of secondary branches per plant, no. of siliquae per plant, length of siliquae, no. of seeds per siliquae and protein content.

*, ** Significant at 5 and 1 per cent levels, respectively