Electronic Journal of Plant Breeding, 8(1): 51-58 (March 2017)
ISSN 0975-928X
DOI: 10.5958/0975-928X.2017.00007.2

Research Article

Studies on combining ability and heterosis using cytoplasmic male sterility system in Indian mustard [*Brassica juncea* (L.) Czern & Coss.]

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(Received: 16 April 2015; Revised: 03 Feb 2017; Accepted: 12 Feb 2017)

Abstract
A field experiment on Indian mustard consisting thirty two parents (two lines + thirty testers) and their sixty crosses was conducted to estimate general and specific combining ability of parents and crosses, respectively. The variances due to SCA were higher than GCA variances for almost all traits, confirming the presence of non-additive gene action in the inheritance of these characters. Among testers, NDRE-22, EJ-22, RH-919, Divya-22, NDRE-08-04, NPJ-135, PRE-2009-09, NPJ-148 and PRE-2007-06 were found good general combiners for seed yield. The crosses, CMSMori x NPJ-135 (13.17 %) and CMSNDRE-4 x PRE-2007-06 (12.83 %) showed significant *sca* effect and heterosis over standard varieties Kranti and Maya, respectively.

Key words
Combining ability, Indian mustard, seed yield and CMS

Introduction

The prime objective in Indian mustard breeding is to achieve high production and productivity. This can be achieved by successful exploitation of hybrid vigour, which would depend upon the identification of hybrids that are more productive than either of the parents and standard check cultivars. For the purpose, the availability of suitable and stable male sterility, fertility restorer system may be best tools for achieving the goal. At present, cytoplasmic male sterility system (CMS) has been discovered in *B. juncea* (Rawat and Anand, 1979; Pradhan *et. al.,* 1991) and raised hope that hybrids in *Brassica* would soon be reality with stable performance. Combining ability analysis is useful technique for understanding the relative magnitude of GCA and SCA variances. The high yield in F_1 may be due to fixable (additive and additive x additive epitasis) or non-fixable (non-additive) type of gene actions. The selection of parents having high genetic potential is crucial as analyzing and handling of very large number of crosses resulting from numerous parents would be an unrealistic and perhaps impossible task. More than 20 % heterosis has been recorded in Indian mustard with respect to seed yield and its attribute traits has been reported with hybrids showing greater advantage under adverse environmental conditions (Banga and Labana, 1984 and Dhillon *et al*., 1990). Hence, the present investigation was envisaged to study the general and specific combining ability effects.

Materials and methods

The experimental materials comprised of two lines, 30 testers and their 60 crosses were evaluated in a randomized block design with three replications at Research Farm of Genetics and Plant Breeding of N.D. University of Agriculture and Technology, Kumarganj, Faizabad (U.P.) during *Rabi* 2011-12. Each entry was accommodated in a single row of 5 meter length with row to row and plant to plant distances of 30 cm and 15 cm, respectively. All the recommended package of practices were followed throughout the crop growth to establish successful crop stand. The data were recorded on five randomly selected plants leaving border plants in each replication for days to 50 per cent flowering, days to maturity, plant height (cm), number of primary branches per plant, number of secondary branches per plant, length of main raceme (cm), number of siliquae on main raceme, number of seeds per siliqua, 1000-seed weight (g), biological yield (g), harvest Index (%), oil content (%) and seed yield per plant (g). The oil content was estimated by NIR on dry seed basis. The data were subjected to 'line x tester' analysis for combining ability (Kempthorne, 1957) and standard heterosis (Fonseca and Patterson, 1968).

Results and discussion

The analysis of variance revealed highly significant differences among parents as well as crosses for all the characters except number of primary branches per plant. Variances due to parents *vs* crosses were also highly significant for all the characters except biological yield. Variances due to lines x testers were significant for days to 50 per cent flowering, days to maturity, plant height, biological yield, oil content, number of primary branches per plant and number of secondary branches per plant. The variances due to lines revealed significant differences for days to 50 per cent flowering, number of siliquae on main raceme, biological yield and length of main raceme. The variances due to testers also revealed significant differences for all the character except

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number of primary branches per plant (Table-1). These results are in agreement with the findings of Lalta *et al.* (2002) and Singh *et al.* (2005).

Based on *gca* effect, the important traits *viz*., 1000-seed yield, CMSMori among lines and Kranti, Kargil selection, DRMREJ-2010-02, NDRE-04, NPJ-147, NPJ-112, PRE-2007-06, EJ-22, NML-100, DRMR-904, RH-0749, RH-0704, Divya-22, HYT-33, NPJ-149 and RGN-73 among testers, showed significant positive good combiners (table-2). HYT-33 have found good combiners for plant height, number of secondary branches per plant, length of main raceme, number of siliquae on main raceme and 1000-seed yield. Moreover, six characters in desirable positive direction and two characters in desirable negative direction have been reported as good combiners for Divya-22. For harvest index, Divya-22 and RGN-73 were found good combiners. Besides, NDRE-22, EJ-22, RH-919, Divya-22, NDRE-08-04, NPJ-135, PRE-2009-09, NPJ-148 and PRE -2007-06 among testers were identified as superior donors for seed yield. The higher estimate of GCA effects for seeds yield were found to be associated with higher gca effects mainly for number of primary branches per plant, number of seeds per siliqua and biological yield.

The hybrids exhibited consistently high and significant and positive *sca* effects for all the characters, studies. The maximum merits of significant and positive *sca* effects in desirable direction are presented in Table 3 and 4. Specific combining ability (SCA) is associated with interaction effects, which may be dominance and epitasis components of variation that are non-fixable in nature. The promising F_1's exhibiting significant *sca* effects in desirable direction may be exploit as hybrids in future Indian mustard improvement programme. Best cross combinations based on desirable *sca* effects and high *per se* performance for seed yield were CMSMori x NPJ-135, CMSNDRE-4 x PRE-2007-06, CMSMori x NPJ-147, and CMSNDRE-4 x DRMREJ-2010-01. In the study average degree of dominance, biological yield, number of primary branches per plant, harvest index, number of siliquae on main raceme and length of main raceme were governed by non-additive gene action indicating the scope of genetic improvement in Indian mustard through exploitation of hybrid vigour. Similarly, the predominant role of non-additive gene action in the expression of various quantitative traits including seed yield in mustard has been reported by Mohan *et al*. (2011) and Singh *et al.* (2012). The two common crosses showing maximum heterosis for oil content over SV_1 were CMSNDRE-4 x PRE-2007-06 and CMSNDRE-4 x DRMREJ-2010-02 and four common crosses found maximum heterosis over SV_2 were CMSNDRE-4 x PRE-2007-06, CMSMori x NDRE-08-04, CMSMori x NDRE-07 and CMSNDRE-4 x DRMREJ-2010-02. Thus, The genotype/ testers NDRE-22, followed by EJ-22, RH-919, Divya-22, NDRE-08-04, NPJ-135, PRE-2009-09, NPJ-148 and PRE-2007-06 proved good general combiners and the crosses CMSMori x NPJ-135, CMSNDRE-4 x PRE-2007-06, CMSMori x NPJ-147 and CMSNDRE-4 x DRMREJ-2010-01 were found best specific combiners for seed yield.

In the present study, best cross combinations based on desirable *sca* effects and high *per se* performance for seed yield were, CMSMori x NPJ-135, CMSNDRE-4 x PRE-2007-06, CMSMori x NPJ-147, and CMSNDRE-4 x DRMREJ-2010-01. Additionally, the crosses *viz.*, CMSMori x NPJ-135 and CMSNDRE-4 x PRE-2007-06 were also reported good specific combiners as well as high heterotic over both the standard varieties *i.e.*, Kranti and Maya. This indicated the existence of positive association between SCA effects and heterotic response.

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Table 1. Analysis of variance for combining ability for 13 characters in L x T mating design in Indian mustard

Characters	Source of variation							
	Replication	Parents	Parents *vs* crosses	Crosses	Lines	Testers	Line x testers	Error
Degrees of freedom	2	31	1	59	1	29	1	182
Days to 50% flowering	1.15	77.86**	79.78**	71.20**	16.16**	80.83**	52.91**	0.69
Days to maturity	4.92*	84.91**	6.75**	51.51**	0.17	90.26**	14.62**	1.28
Plant height (cm)	2.55	488.67**	17468.00**	748.72**	48.57	455.67**	1885.95**	29.88
No. of primary branches per plant	0.31	0.30	34.39**	0.55**	0.01	0.27	1.59*	0.24
No. of secondary branches per plant	1.99	14.94**	177.92**	5.16**	1.32	15.73**	5.61*	0.87
Length of main raceme (cm)	16.46	346.37**	1878.96**	157.87**	81.27*	364.85**	75.73	21.15
No. of siliquae on main raceme	1.80	81.25**	1331.50**	76.01**	48.34**	84.95**	6.73	3.30
No. of seeds per siliqua	2.24*	6.00**	32.66**	4.93**	1.73	6.31**	1.10	0.57
1000-seed weight (g)	0.04	0.95**	19.14**	2.06**	0.04	1.01**	0.05	0.06
Biological yield (g)	7.35	32.77**	0.26	41.57**	162.76**	33.96**	30.92**	3.04
Harvest index (%)	8.00**	11.37**	48.89**	2.13*	0.06	12.15**	0.39	1.28
Oil content (%)	0.28	4.70**	15.45**	1.18**	0.85	4.91**	2.66**	0.37
Seed yield per plant (g)	1.59	1.73**	6.79**	3.70**	0.002	1.79**	1.55	0.53

*, ** significant at 5 and 1 per cent probability levels, respectively.

Table 2. Studies of GCA effects of parents (females and males) for 13 characters in Indian mustard

S. No.	Parents	DFF	DM	PH	PB	SB	LMR	SMR	SS	1000-SW	BY	HI	OC	SY
Lines														
1	CMSNDRE-4	0.07	-0.01	-8.43**	-0.04	-0.06	-2.42**	-1.88**	-0.14*	-0.15**	0.46*	-0.14	0.01	0.1
2	CMSMori	-0.07	0.01	8.43**	0.04	0.06	2.42**	1.88**	0.14*	0.15**	-0.46*	0.14	-0.01	-0.1
	SE (gi) Lines	**0.08**	**0.12**	**0.58**	**0.05**	**0.09**	**0.48**	**0.19**	**0.07**	**0.02**	**0.18**	**0.12**	**0.06**	**0.07**
	SE(gi – gj)	**0.12**	**0.17**	**0.81**	**0.07**	**0.14**	**0.68**	**0.27**	**0.11**	**0.04**	**0.25**	**0.17**	**0.09**	**0.1**
Testers														
1	Kranti	5.58**	-3.52**	-20.39**	0.04	0.21	-1.19	1.28	-0.04	0.47**	-2.43**	-0.84	0.3	-0.94**
2	IC-355399	-0.25	-2.35**	6.86**	-0.34	-2.32**	-5.70**	-1.19	1.09**	0.29**	-0.76	0.01	-0.85**	-0.27
3	DRMREJ-2010-02	-2.08**	-0.68	6.63**	-0.61**	-1.56**	4.66*	0.58	-0.31	0.03**	1.57*	0.17	1.04**	0.49
4	NDRE-1	-7.75**	-3.02**	-23.90**	-0.28	-0.26	-2.72	-4.99**	-1.34**	0.81**	-0.43	-0.57	-0.02	-0.29
5	PRE-2009-9	-2.58**	0.32	1.46	0.06	0.61	-11.60**	-6.15**	1.49**	-0.75**	1.74*	0.53	0.28	0.66*
6	NDRE-7	-8.25**	-2.52**	-10.44**	-0.28	0.51	-1.8	-1.92*	-0.27	-0.47**	-3.76**	-1.09*	-0.58*	-1.37**
7	NPJ-148	-4.92**	-5.85**	-6.37**	-0.31	-0.32	-3.50*	-1.19	-0.24	-0.64**	-1.43*	-1.10*	0.18	-0.76*
8	RRN-693	-5.42**	-3.35**	7.26**	-0.61**	-0.39	5.26**	0.91	-1.24**	-0.11**	1.41*	0.46	0.05	0.54
9	NPJ-147	-1.92**	-1.35**	-2.14	0.46*	2.14**	-1.57	-0.59	-0.34	0.04**	2.41**	-0.05	0.48	0.61*
10	NDRE-08-04	-6.92**	-2.18**	-5.14*	-0.08	1.24**	3	-2.12**	-0.71*	-0.75**	2.91**	0.45	-0.92**	0.96**
11	RH-919	-0.42	0.15	-5.57*	0.32	1.01**	-7.07**	-3.05**	2.16**	-0.71**	-3.93**	0.11	0.52*	-0.89**
12	EJ-17	-0.08	-3.68**	-0.24	-0.18	0.04	1.43	-1.35	0.86**	-0.07**	-2.93**	-0.44	-0.07	-0.96**
13	NPJ-112	-3.08**	-4.68**	-14.50**	0.26	-1.52**	-5.30**	-5.45**	0.66*	0.62**	-2.26**	0.17	0.09	-0.64*
14	DRMREJ-2010-01	-2.75**	-4.02**	-5.50*	-0.21	-0.06	4.23*	2.48**	2.33**	-0.52**	0.41	-0.61	0.14	-0.11
15	NDRE-22	-5.75**	-1.52**	-8.10**	0.52**	0.34	-2.7	-0.72	0.69*	-0.17**	5.07**	0.68	-0.04	1.66**

*, ** significant at 5 and 1 per cent probability levels, respectively, DFF= Days to 50% flowering, DM=Days to maturity, PH= Plant height, PB= Primary branches/plant, SB=Secondary branches/plant, LMR=Length of main raceme, SMR=Siliquae on main raceme, SS=Seeds/siliqua, 1000-SW= 1000-seed weight, BY=Biological yield, HI=Harvest index, OC=Oil content, SY=Seed yield/plant

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ISSN 0975-928X
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Table 2. Contd.,

S. No.	Parents	DFF	DM	PH	PB	SB	LMR	SMR	SS	1000-SW	BY	HI	OC	SY
16	JD-06	-0.25	-5.02**	1.46	0.29	0.34	-2.2	2.71**	0.26	0	1.24	-1.42**	0.23	-0.11
17	DRMRIJ-258	-0.42	-1.02*	-0.2	-0.04	-0.69	-9.37**	-3.42**	-1.11**	-0.60**	-1.09	0.22	-0.05	-0.27
18	PRE-2007-06	-0.92**	-2.68**	-0.77	0.09	0.78*	-1.47	-1.62*	-0.24	0.12**	1.24	0.76	-0.05	0.61*
19	EJ-22	2.75**	0.15	1.33	0.32	-1.12**	11.96**	9.38**	0.03	0.08**	5.07**	0.33	0.39	1.53**
20	NML-100	-0.25	0.32	-8.84**	-0.48*	-1.52**	1.03	2.78**	-1.17**	0.43**	-4.76**	0.53	0.2	-1.17**
21	NPJ-135	-4.92**	-1.85**	11.30**	0.39	0.38	-5.50**	0.61	0.66*	-0.54**	2.41**	0.71	-0.25	0.91**
22	DRMR-904	6.08**	5.65**	-13.04**	0.19	-0.59	-3.64*	-1.79*	-1.41**	0.31**	-2.76**	-0.22	0.27	-0.84**
23	RH-0749	6.58**	7.15**	13.06**	-0.08	-0.02	-0.4	0.88	0.73*	0.45**	-0.59	0.28	0.17	-0.09
24	RH-0704	6.42**	8.82**	16.63**	0.06	0.41	4.70*	4.91**	-0.71*	0.26**	-0.43	-0.02	-0.03	-0.11
25	Divya-22	3.75**	6.48**	15.73**	0.12	1.31**	1.9	-0.99	0.16	0.72**	2.91**	0.93*	0.38	1.08**
26	HYT-33	6.75**	7.15**	6.61**	0.39	2.08**	6.03**	4.11**	-1.24**	1.12**	-2.09**	0.19	0.04	-0.64*
27	NPJ-149	8.58**	0.15	1.03	-0.01	0.51	5.80**	4.05**	-0.17	0.48**	4.91**	0.25	0.12	1.44**
28	Divya-33	5.75**	6.82**	17.66**	-0.14	-0.92*	8.33**	3.38**	-0.97**	-0.65**	-2.76**	-0.65	-0.52*	-0.97**
29	RGN-73	6.75**	3.48**	15.43**	0.06	-0.96*	4.66*	-3.05**	0.56	0.24**	3.09**	0.98*	-0.67*	-0.61*
30	Maya	-0.08	2.65**	2.63	0.12	0.31	2.8	1.45	-0.17	-0.49**	2.24**	-0.33	-0.84**	0.51
	SE(gi) Testers	**0.33**	**0.46**	**2.23**	**0.2**	**0.38**	**1.87**	**0.74**	**0.3**	**0.01**	**0.71**	**0.46**	**0.25**	**0.29**
	SE(gi – gj)	**0.48**	**0.65**	**3.15**	**0.28**	**0.54**	**2.65**	**1.04**	**0.43**	**0.14**	**1.01**	**0.65**	**0.35**	**0.42**

*, ** significant at 5 and 1 per cent probability levels, respectively, DFF= Days to 50% flowering, DM=Days to maturity, PH= Plant height, PB= Primary branches/plant, SB=Secondary branches/plant, LMR=Length of main raceme, SMR=Siliquae on main raceme, SS=Seeds/siliqua, 1000-SW= 1000-seed weight, BY=Biological yield, HI=Harvest index, OC=Oil content, SY=Seed yield/plant

Table 3. Studies of SCA effects of crosses for 13 characters in Indian mustard

S. No.	Crosses	DFF	DM	PH	PB	SB	LMR	SMR	SS	1000-SW	BY	HI	OC	SY
1	CMSNDRE-4 x Kranti	0.26	0.84	2.85	0.2	0.49	-0.89	0.78	-0.4	0.37*	0.37	-0.3	-0.62	-0.03
2	CMSNDRE-4 x IC-355399	0.43	0.01	-11.80**	0.24	0.36	0.29	-4.15**	-0.93*	0.12	3.37**	-1.0	-0.5	0.64
3	CMSNDRE-4 x DRMREJ-2010-02	0.59	0.67	-3.77	0.04	-0.47	-1.88	-1.99	0.54	0.03	-0.96	-0.2	0.73*	-0.4
4	CMSNDRE-4 x NDRE-1	0.26	0.34	-4.77	-0.23	-0.64	-1.03	-2.35*	-1.36**	-0.22	1.71	-0.5	-0.34	0.29
5	CMSNDRE-4 x PRE-2009-9	-0.24	0.67	1.73	0.24	0.63	-0.54	-2.99**	-1.06*	-0.1	0.21	-1	-0.17	-0.3
6	CMSNDRE-4 x NDRE-7	0.43	-0.16	5.16	-0.3	0.06	-3.34	-4.22**	0.44	0.29*	0.04	-1	-0.77*	-0.26
7	CMSNDRE-4 x NPJ-148	-0.91	0.51	-2.24	-0.13	-0.24	0.96	0.65	0.07	0.06	-0.63	-0.1	0.02	-0.18
8	CMSNDRE-4 x RRN-693	0.26	-0.33	-7.34*	-0.03	1.76**	-3.68	-1.25	-0.2	-0.53**	2.21*	0.63	-0.29	0.82
9	CMSNDRE-4 x NPJ-147	0.76	0.67	1.8	-0.1	-0.04	3.49	2.38*	-0.23	-1.02**	-5.79**	0.93	0.46	-1.31*
10	CMSNDRE-4 x NDRE-08-04	-0.91	0.84	5.66	-0.43	-0.41	3.39	4.85**	-1.26**	-0.13	-2.96**	0.14	-0.89*	-0.8
11	CMSNDRE-4 x RH-919	-0.74	0.51	9.03**	0.17	1.09*	-1.68	0.05	-0.93*	-0.22	0.21	0.45	-0.11	0.12
12	CMSNDRE-4 x EJ-17	-0.41	-0.66	1.3	0.27	-0.27	-4.93	-0.45	0.64	-0.62**	0.21	-0.2	0.42	-0.01
13	CMSNDRE-4 x NPJ-112	0.26	0.67	-1.24	-0.03	-0.17	-1.64	-0.99	0.57	-1.12**	-1.46	0.05	0.16	0.46
14	CMSNDRE-4 x DRMREJ-2010-01	-1.07*	0.01	5.3	-0.1	0.76	-4.11	-2.55*	0.37	-0.03	4.21**	0.39	-0.38	1.27*
15	CMSNDRE-4 x NDRE-22	0.26	-1.49*	6.83*	-0.56*	-1.77**	7.56*	4.18**	0.8	-0.59**	-1.13	-0.3	-0.48	-0.43
16	CMSNDRE-4 x JD-06	0.09	-0.66	8.53**	0.27	-1.11*	4.52	0.75	-0.03	-0.53**	0.37	0.58	0.2	0.3
17	CMSNDRE-4 x DRMRIJ-258	0.26	-0.33	-7.94*	0.07	0.33	0.89	1.88	10.7**	0.37*	0.71	0.58	0.34	0.37
18	CMSNDRE-4 x PRE-2007-06	-0.91	-0.33	7.90*	-0.06	0.46	1.79	3.21**	-0.66	-0.49**	4.71**	0.58	0.97**	1.52**
19	CMSNDRE-4 x EJ-22	-0.57	0.51	-2.8	0.37	-0.24	-0.51	1.08	0.14	-0.29*	0.21	1.11	-0.7	0.44
20	CMSNDRE-4 x NML-100	-0.57	-0.66	5.76	-0.43	-0.91	2.96	3.68**	0.2	-0.82**	2.04*	0.57	-0.2	0.74
21	CMSNDRE-4 x NPJ-135	0.43	-0.49	-11.77**	0.64*	0.19	-0.64	-3.69**	0.84	0.05	-5.46**	0	0.32	-1.55**
22	CMSNDRE-4 x DRMR-904	0.09	-0.33	-20.24**	-0.3	-1.11*	-13.31**	-8.62**	-1.10*	0.90**	-0.96	0.93	0.18	0
23	CMSNDRE-4 x RH-0749	0.26	0.17	8.13*	0.3	0.99	7.59*	8.18**	0.64	1.15**	-4.13**	-0.3	0.25	-1.28**
24	CMSNDRE-4 x RH-0704	0.09	0.17	-6.50*	0.04	0.23	-2.71	-0.65	-0.93*	1.39**	2.04*	-0	-0.3	0.6
25	CMSNDRE-4 x Divya-22	0.09	0.51	-1.74	0.24	1.26*	-1.91	-0.35	1.47**	1.29**	2.04*	-0.6	-0.04	0.35
26	CMSNDRE-4 x HYT-33	0.09	-0.83	-7.25*	-0.43	0.23	0.02	-1.72	-1.00*	0.89**	-1.96	-0.2	0.42	-0.6
27	CMSNDRE-4 x NPJ-14 9	0.59	-0.16	1.5	0.57	0.26	-3.81	-0.59	0.2	0.2	0.71	-0	-0.31	0.19
28	CMSNDRE-4 x Divya-33	0.43	-0.83	21.66**	-0.5	-1.57**	1.39	0.08	0.6	-0.17	0.04	0.02	-0.15	0
29	CMSNDRE-4 x RGN-73	-0.24	-0.16	-3.57	0.1	-0.14	9.59**	3.91**	1.60**	-0.07	1.71	-0.2	0.5	0.44
30	CMSNDRE-4 x Maya	0.59	0.34	-0.17	-0.1	-0.01	1.39	0.88	-0.06	-0.17	-1.63	-0.1	0.57	-0.48
31	CMSMori x Kranti	-0.26	-0.84	-2.85	-0.2	-0.49	0.89	-0.78	0.4	-0.37*	-0.37	0.33	0.62	0.03

*, ** significant at 5 and 1 per cent probability levels, respectively, DFF= Days to 50% flowering, DM=Days to maturity, PH= Plant height, PB= Primary branches/plant, SB=Secondary branches/plant, LMR=Length of main raceme, SMR=Siliquae on main raceme, SS=Seeds/siliqua, 1000-SW= 1000-seed weight, BY=Biological yield, HI=Harvest index, OC=Oil content, SY=Seed yield/plant

Table 3. Contd.,

S. No.	Crosses	DFF	DM	PH	PB	SB	LMR	SMR	SS	1000-SW	BY	HI	OC	SY
32	CMSMori x IC-355399	-0.43	-0.01	11.80**	-0.24	-0.36	-0.29	4.15**	0.93*	-0.12	-3.37**	0.96	0.5	-0.64
33	CMSMori x DRMREJ-2010-02	-0.59	-0.67	3.77	-0.04	0.47	1.88	1.99	-0.54	-0.03	0.96	0.18	-0.73*	0.4
34	CMSMori x NDRE-1	-0.26	-0.34	4.77	0.23	0.64	1.03	2.35*	1.36**	0.22	-1.71	0.51	0.34	-0.29
35	CMSMori x PRE-2009-9	0.24	-0.67	-1.73	-0.24	-0.63	0.54	2.99**	1.06*	0.1	-0.21	0.99	0.17	0.3
36	CMSMori x NDRE-7	-0.43	0.16	-5.16	0.3	-0.06	3.34	4.22**	-0.44	-0.29*	-0.04	0.95	0.77*	0.26
37	CMSMori x NPJ-148	0.91	-0.51	2.24	0.13	0.24	-0.96	-0.65	-0.07	-0.06	0.63	0.06	-0.02	0.18
38	CMSMori x RRN-693	-0.26	0.33	7.34*	0.03	-1.76**	3.68	1.25	0.2	0.53**	-2.21*	-0.6	0.29	-0.82
39	CMSMori x NPJ-147	-0.76	-0.67	-1.8	0.1	0.04	-3.49	-2.38**	0.23	1.02**	5.79**	-0.9	-0.46	1.31**
40	CMSMori x NDRE-08-04	0.91	-0.84	-5.66	0.43	0.41	-3.39	-4.85**	1.26**	0.13	2.96**	-0.1	0.89*	0.8
41	CMSMori x RH-919	0.74	-0.51	-9.03**	-0.17	-1.09*	1.68	-0.05	0.93*	0.22	-0.21	-0.5	0.11	-0.12
42	CMSMori x EJ-17	0.41	0.66	-1.3	-0.27	0.27	4.93	0.45	-0.64	0.62**	-0.21	0.18	-0.42	0.01
43	CMSMori x NPJ-112	-0.26	-0.67	1.24	0.03	0.17	1.64	0.99	-0.57	1.12**	1.46	-0.1	-0.16	-0.46
44	CMSMori x DRMREJ-2010-01	1.07*	-0.01	-5.3	0.1	-0.76	4.11	2.55*	-0.37	0.03	-4.21**	-0.4	0.38	-1.27**
45	CMSMori x NDRE-22	-0.26	1.49*	-6.83*	0.56*	1.77**	-7.56**	-4.18**	-0.8	0.59**	1.13	0.25	0.48	0.43
46	CMSMori x JD-06	-0.09	0.66	-8.53**	-0.27	1.11*	-4.52	-0.75	0.03	0.53**	-0.37	-0.6	-0.2	-0.3
47	CMSMori x DRMRIJ-258	-0.26	0.33	7.94*	-0.07	-0.33	-0.89	-1.88	-1.07	-0.37*	-0.71	-0.6	-0.34	-0.37
48	CMSMori x PRE-2007-06	0.91	0.33	-7.90*	0.06	-0.46	-1.79	-3.21**	0.66	0.49**	-4.71**	-0.6	-0.97**	-1.52**
49	CMSMori x EJ-22	0.57	-0.51	2.8	-0.37	0.24	0.51	-1.08	-0.14	0.29*	-0.21	-1.1	0.7	-0.44
50	CMSMori x NML-100	0.57	0.66	-5.76	0.43	0.91	-2.96	-3.68**	-0.2	0.82**	-2.04*	-0.6	0.2	-0.74
51	CMSMori x NPJ-135	-0.43	0.49	11.77**	-0.64*	-0.19	0.64	3.69**	-0.84	-0.05	5.46**	0	-0.32	1.55**
52	CMSMori x DRMR-904	-0.09	0.33	20.24**	0.3	1.11*	13.31**	8.62**	1.10*	-0.90**	0.96	-0.9	-0.18	0
53	CMSMori x RH-0749	-0.26	-0.17	-8.13*	-0.3	-0.99	-7.59**	-8.18**	-0.64	-1.15**	4.13**	0.27	-0.25	-1.28**
54	CMSMori x RH-0704	-0.09	-0.17	6.50*	-0.04	-0.23	2.71	0.65	0.93*	-1.39**	-2.04*	0.02	0.3	-0.6
55	CMSMori x Divya-22	-0.09	-0.51	1.74	-0.24	-1.26*	1.91	0.35	-1.47**	-1.29**	-2.04*	0.57	0.04	-0.35
56	CMSMori x HYT-33	-0.09	0.83	7.25*	0.43	-0.23	-0.02	1.72	1	-0.89**	1.96	0.19	-0.42	0.6
57	CMSMori x NPJ-149	-0.59	0.16	-1.5	-0.57*	-0.26	3.81	0.59	-0.2	-0.2	-0.71	0.01	0.31	-0.19
58	CMSMori x Divya-33	-0.43	0.83	-21.66**	0.5	1.57**	-1.39	-0.08	-0.6	0.17	-0.04	-0	0.15	0
59	CMSMori x RGN-73	0.24	0.16	3.57	-0.1	0.14	-9.59**	-3.91**	-1.60**	0.07	-1.71	0.21	-0.5	-0.44
60	CMSMori x Maya	-0.59	-0.34	0.17	0.1	0.01	-1.39	-0.88	0.06	0.17	1.63	0.06	-0.57	0.48
	SE (S_{ij})	**0.48**	**0.65**	**3.15**	**0.28**	**0.54**	**2.65**	**1.04**	**0.43**	**0.14**	**1.01**	**0.65**	**0.35**	**0.42**
	SE ($S_{ij} - S_{kl}$)	**0.67**	**0.92**	**4.46**	**0.4**	**0.76**	**3.75**	**1.48**	**0.62**	**0.2**	**1.42**	**0.92**	**0.5**	**0.59**

*,** significant at 5 and 1 per cent probability levels, respectively, DFF= Days to 50% flowering, DM=Days to maturity, PH= Plant height, PB= Primary branches/plant, SB=Secondary branches/plant, LMR=Length of main raceme, SMR=Siliquae on main raceme, SS=Seeds/siliqua, 1000-SW= 1000-seed weight, BY=Biological yield, HI=Harvest index, OC=Oil content, SY=Seed yield/plant

Table 4. Prospective cross combinations based on desirable SCA effects for seed yield and oil content in Indian mustard

Characters	Cross Combinations	SCA effects	Heterosis (%)		Other characters with significant *sca* effects
			SV_1	SV_2	
Seed yield per plant (g)	CMSMori x NPJ-135	1.55**	13.17*	12.83*	PH, PBP, NSR, BY, SY
	CMSNDRE-4 x PRE-2007-06	1.52**	11.75*	11.41	PH, NSR, TW, BY, OC, SY
	CMSMori x NPJ-147	1.31*	7.70	7.37	NSR, TW, BY, SY
	CMSNDRE-4 x DRMREJ-2010-01	1.27*	2.03	1.72	DFF, NSR, BY, SY
Oil content (%)	CMSNDRE-4 x PRE-2007-06	0.97**	3.44**	7.86**	PH, NSR, TW, BY, OC, SY
	CMSMori x NDRE-08-04	0.89**	1.11	5.43**	NSR, NSS, BY, OC
	CMSMori x NDRE-07	0.77**	1.65	5.99**	NSR, TW, OC
	CMSNDRE-4 x DRMREJ-2010-02	0.73**	5.52**	10.03*	OC

*, ** significant at 5 and 1 per cent probability levels, respectively,
DFF= Days to 50% flowering, PH= Plant height, PBP= Primary branches/plant, NSR=Secondary branches/plant, TW= 1000-seed weight, BY=Biological yield, OC=Oil content, SY=Seed yield/plant