Received:01 Sep 2020 | Revised: 08 Aug 2021 | Accepted: 10 Aug 2021

Electronic Journal of Plant Breeding

Research Article

Combining ability analysis in Indian mustard [*Brassica juncea (L.) Czern & Coss.]* involving Ogura CMS system

Neeraj Kumar*, Ram Avtar and Vivek K. Singh

Department of Genetics and Plant Breeding, College of Agriculture, CCS Haryana Agricultural University, Hisar-125004
***E-Mail:** neerajkummar8@gmail.com

Abstract
Line × tester analysis was carried out to estimate combining ability of *Ogura* CMS based hybrids in Indian mustard *[Brassica juncea* (L.) Czern & Coss.]. For this, 50 hybrids were developed by crossing five *Ogura* CMS lines with ten restorers according to the Line x Tester mating design. A total of 65 genotypes including 50 hybrids and 15 parents were evaluated during *Rabi*, 2017-18. Analysis of variance revealed significant differences among lines and crosses for most of the traits. The value of σ^2SCA/σ^2GCA was found less than one, for most of the traits indicating a major role of non-additive gene action in the expression of characters. Line RH 0555-OA and tester IOR-12 were found to be good general combiners possessing highly significant and positive *gca* effects for seed yield and component traits. The cross RH 0630-OA × IOR-12 had expressed the highly significant and positive *sca* effects for seed yield per plant. Other crosses such as RH 8812-OA × IOR-3, RH 0749-OA × IOR-6, RH 0749-OA × IOR-22, RH 0749-OA × IOR-18 and RH 0630-OA × IOR-11 had exhibited significant *sca* effects for different yield related characters in Indian mustard.

Key words: GCA, SCA, Ogura CMS, Indian mustard

INTRODUCTION

Brassica juncea (Linn.) Czern & Coss commonly known as Indian mustard belongs to the family Brassicacae and genus Brassica. It is a natural amphidiploid (2n = 36) of *Brassica rapa* (2n = 20) and *Brassica nigra* (2n = 16) (Patel *et al*., 2021). This crop is one of the important oilseeds crops of India. India meets 57 per cent of the domestic edible oil requirements through imports and is ranked the 7th largest importer of edible oils in the world. The further boom in human population and improved living standards has led to a rapid increase in per capita oil consumption. Thus, there is an urgent need to increase the yield potential through genetic interventions to meet the present and future oil requirements. Ghosh *et al*. (2002) suggested that heterosis breeding could be a potential alternative to substantially increase the productivity of Indian mustard. Attempts for the exploitation of hybrid vigour have been stimulated by the availability of a large number of CMS sources such as *nap, polima, ogura, tournefortii, axyrrhina* etc. Among these, *ogura* (Ogu) CMS shows complete sterility and also stable. Hence, *ogura* CMS system is suitable for the hybrid development in Indian mustard.

Commercial hybrid development depends upon the combining ability of parents and the presence of significant heterosis. Previous studies have shown that parents with good *per se* performance might not produce useful progenies when used in hybridization. The selection of appropriate parents for the improvement of elite hybrid depends on the selection of parents based on combining ability (Gnanasekaran and Thiyagu, 2021). Combining ability also gives information about the nature of gene action responsible for the inheritance of quantitative traits. Line x Tester mating design of Kempthorne (1957) is one of the most efficient methods for estimating the combining ability of parents and crosses. This method also provides information about the nature of gene action involved in the expression of traits (Singh and Chaudhury, 1977).

MATERIALS AND METHODS

This study aimed to evaluate *gca* of parental lines along with *sca* of the crosses. The experimental material for this study is comprised of five *Ogura* CMS lines and ten restorers as testers. Fifty F_1 hybrids were generated by crossing five CMS lines with ten restorers during *Rabi*, 2016-17 in Line x Tester fashion. The crosses along with their parents were planted in randomized complete block design in three replications during *Rabi*, 2017-18. Each genotype was grown in two rows of four meter length with a spacing of 45 x 15 cm row to row and plant to plant, respectively. Standard agronomic practices were followed to raise the good crop. Recommended doses of fertilizers *viz*., 100:30 kg/ha of N: P respectively, were applied and irrigated twice including pre-sowing irrigation. Observations were recorded on 12 quantitative traits, *viz*., days to 50% flowering, days to maturity, plant height (cm), the number of primary branches per plant, the number of secondary branches per plant, main shoot length (cm), the number of siliquae on main shoot, siliqua length (cm), the number of seeds per siliqua, 1000-seed weight (g), seed yield per plant (g) and oil content (%). The combining ability analysis was carried according to Kempthorne (1957). The calculations were performed through the computer-generated programme WINDOW STAT version 8.6 from INDOSAT Services, Hyderabad, India.

RESULTS AND DISCUSSION

ANOVA of combining ability is presented in **Table 1**. The significant differences among lines were found for the characters *viz*., plant height, number of secondary branches per plant, seed yield per plant and oil content. There were non-significant differences among the testers for all the characters under study. Significant differences due to the Line x Tester interaction were found for all the characters except for plant height. The SCA variances (σ^2SCA) were found greater in magnitude than GCA variance (σ^2GCA) for all the characters except for plant height (**Table 2**). The value of σ^2SCA/σ^2GCA was less than one for all the characters except for plant height indicating a major role of non-additive gene action (dominance and epistasis) in the expression of these traits. Gupta *et al*. (2011) and Meena *et al*. (2015) also reported similar results in Indian mustard.

Table 1. Analysis of variance for parents and hybrids for seed yield and quality characters in Indian mustard

Source	df	Days to 50% flowering	Days to maturity	Plant height	Number of primary branches /plant	Number of secondary branches/ plant	Main shoot length	Number of siliqua on main shoot	Siliqua length	Number of seeds/ siliqua	1000-seed weight	Seed yield / plant	Oil content
Replication	2	0.65	0.87	278.13	1.01	0.89	17.07	20.28	0.10	1.34	0.04	0.14	0.10
Treatments	64	14.04**	25.35**	279.79**	2.36**	24.64**	163.91**	101.64**	0.61**	9.05**	1.79**	87.66**	1.74**
Parents	14	34.59**	62.76**	588.30**	0.68	23.72**	281.67**	171.24**	2.09**	18.43**	5.8**	47.77**	1.94**
Parents (Lines)	4	58.00**	112.93**	374.22**	1.05	10.54**	30.82	49.24	5.27**	4.60**	0.30	19.46**	0.09
Parents (Testers)	9	24.16**	41.89**	150.26	0.55	31.17**	393.37**	189.48**	0.26**	2.94*	1.33**	28.11**	2.76**
Parents (L vs. T)	1	34.84**	49.88**	5387.04**	0.36	9.35	279.74*	495.10**	5.90**	213.07**	68.09**	337.87**	2.00**
Parents vs. Crosses	1	60.72**	32.50**	333.87	3.82**	7.66	602.19**	3.73	0.02	183.00**	6.17**	1904.31**	0.62
Crosses	49	7.22**	14.52**	190.54**	2.81**	25.25**	121.32**	83.75**	0.20**	2.82**	0.56**	61.98**	1.71**
Line effects	4	13.29	22.08	945.30**	4.19	127.75**	170.70	107.42	0.36	3.56	0.62	280.33**	5.86**
Tester effects	9	3.40	5.89	138.65	3.10	21.36	31.64	68.06	0.26	3.09	0.71	63.18	1.07
L x T effects	36	7.50**	15.83**	119.65	2.59**	14.84**	138.26**	85.04**	0.17**	2.68**	0.52**	37.42**	1.41**
Error	128	0.73	1.28	95.50	0.50	2.42	60.27	20.37	0.06	0.89	0.13	3.87	0.24
Total	194	5.12	9.22	158.18	1.12	9.74	94.02	47.18	0.25	3.59	0.68	31.47	0.73

* $P \leq 0.05$, ** $P \leq 0.01$

Table 2. Estimates of components of variance for various traits in Indian mustard

Component of variation	Days to 50% flowering	Days to maturity	Plant height	Number of primary branches/ plant	Number of secondary branches/ plant	Main shoot length	Number of siliqua on main shoot	Siliqua length	Number of seeds/ siliqua	1000-seed weight	Seed yield /plant	Oil content
σ^2 lines	0.41	0.69	28.32	0.12	4.17	3.68	2.90	0.01	0.09	0.02	9.21	0.19
σ^2 testers	0.17	0.31	2.88	0.17	1.26	-1.90	3.18	0.01	0.15	0.04	3.95	0.06
σ^2GCA	0.34	0.56	19.84**	0.14*	3.21**	1.82	2.99	0.01**	0.11*	0.02*	7.42**	0.14**
σ^2SCA	2.25**	4.85**	8.05	0.70**	4.14**	25.99**	21.56**	0.04**	0.60**	0.13**	11.18**	0.39**
σ^2GCA/ σ^2SCA	0.15	0.12	2.47	0.20	0.77	0.07	0.14	0.31	0.18	0.18	0.66	0.37

* P ≤ 0.05, ** P ≤ 0.0

The estimates of general combining effects are presented in **Table 3**. The combining ability estimates showed that two lines *viz*., RH 30-OA and RH 0555-OA and four testers *viz*., IOR-1, IOR-12, IOR-19 and IOR-22 exhibited significant positive *gca* effects for seed yield per plant. Line RH 0555-OA and tester IOR-22 exhibited significant desirable *gca* effects for 1000-seed weight; RH 8812-OA, RH 0749-OA, IOR-11 and IOR-4 for days to maturity; RH 8812-OA, RH 30-OA, RH 0630-OA and IOR-3 for plant height; RH 0555-OA, RH 30-OA, IOR-3 and IOR-4 for days to 50% flowering; RH 0555-OA for main shoot length; RH 0555-OA, RH 30-OA, RH 0630-OA, IOR-1 and IOR-12 for the number of primary branches; RH 0555-OA, RH 30-OA, IOR-4, IOR-1 and IOR-12 for secondary branches per plant; RH 0555-OA, RH 0749-OA, IOR-22 and IOR-1 for siliqua length; RH 0555-OA and IOR-12 for number of siliqua on main shoot. Similarly, for number of seeds per siliqua, significant and positive *gca* effects were possessed by RH 0555-OA, RH 30-OA IOR-22 and IOR-1. Among lines, RH 0555-OA was observed as the best

Table 3. General combining ability of parents for different traits in Indian mustard

Parents	Days to 50% flowering	Days to maturity	Plant height	Number of primary branches/ plant	Number of secondary branches/ plant	Main shoot length	Number of siliqua on main shoot	Siliqua length	Number of seeds/ siliqua	1000-seed weight	Seed yield /plant	Oil content
Lines												
RH 8812-OA	0.32**	-0.78**	-2.17*	-0.51**	-1.82**	-1.59	0.23	-0.18**	-0.39**	-0.18**	-3.36**	-0.48**
RH 0749-OA	0.45**	-0.78**	8.21**	-0.28**	-1.37**	-1.02	-2.64**	0.07*	-0.31*	-0.09	-2.11**	0.65**
RH 0630-OA	0.65**	1.25**	-4.04**	0.36**	-1.21**	0.04	0.51	0.00	0.05	0.08	-0.96**	0.09
RH 30-OA	-0.61**	0.39*	-5.22**	0.23*	2.81**	-1.54	-0.66	0.00	0.37*	-0.01	3.04**	0.08
RH 0555-OA	-0.81**	-0.08	3.22*	0.20*	1.59**	4.10**	2.57**	0.11*	0.29*	0.19**	3.39**	-0.34**
SE ±	0.1565	0.2068	1.7842	0.1294	0.2842	1.4174	0.8240	0.0463	0.1720	0.0664	0.3590	0.0890
C.D.95 %	0.3105	0.4104	3.5407	0.2567	0.5640	2.8129	1.6352	0.0919	0.3413	0.1318	0.7125	0.1767
C.D.99%	0.4111	0.5433	4.6870	0.3399	0.7466	3.7235	2.1646	0.1217	0.4517	0.1745	0.9431	0.2339
Testers												
IOR-1	-0.15	-0.15	1.89	0.55**	1.26**	0.82	0.42	0.15*	0.75**	-0.02	1.51**	-0.02
IOR-2	0.39	1.39**	-2.00	-0.61**	0.42	-0.25	-2.34*	-0.06	0.00	-0.13	-0.57	0.06
IOR-3	-0.81**	0.39	-6.45*	-0.45*	-1.65**	1.26	-0.49	-0.11	-0.79**	-0.01	-1.94**	-0.09
IOR-4	-0.48*	-0.75*	1.69	0.33	1.16**	0.76	1.88	-0.08	-0.17	-0.27**	-0.50	0.10
IOR-6	-0.01	-0.41	-2.71	-0.21	-1.63**	0.68	-0.34	-0.14*	-0.46*	0.13	-3.00**	0.23
IOR-11	-0.21	-0.68*	0.22	-0.45*	-0.78	-0.79	-0.65	-0.03	-0.17	0.01	-1.44**	-0.14
IOR-12	0.79**	0.25	4.42	0.75**	1.67**	1.55	4.53**	0.07	0.38	-0.13	3.12**	-0.12
IOR-18	-0.21	-0.35	0.26	-0.19	-0.89*	-2.85	-2.74*	-0.04	-0.12	0.02	-1.32*	0.59**
IOR-19	0.25	0.05	1.89	0.13	0.40	-1.96	1.06	-0.05	0.10	-0.13	2.35**	-0.30*
IOR-22	0.45*	0.25	0.80	0.15	0.04	0.79	-1.32	0.29**	0.48*	0.54**	1.80**	-0.31*
SE ±	0.2213	0.2925	2.5233	0.1830	0.4019	2.0046	1.1653	0.0655	0.2432	0.0939	0.5077	0.1259
C.D.95 %	0.4392	0.5805	5.0074	0.3631	0.7976	3.9780	2.3125	0.1300	0.4826	0.1864	1.0076	0.2498
C.D.99%	0.5813	0.7684	6.6285	0.4806	1.0558	5.2658	3.0611	0.1721	0.6389	0.2468	1.338	0.3307

* P ≤ 0.05, ** P ≤ 0.01.

Table 4. Mean performance of F_1 hybrids for different characters in Indian mustard

S. No	Crosses	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of primary branches per plant	Number of secondary branches per plant	Main shoot length (cm)	Number of siliqua on main shoot	Siliqua length (cm)	Number of seeds per siliqua	1000-seed weight	Seed yield per plant	Oil content (%)
1.	RH 8812-OA × IOR-1	49	139	211	8.6	16.4	81.0	50.4	4.3	13.5	4.3	20.7	38.37
2.	RH 8812-OA × IOR-2	47	135	216	5.3	14.1	74.8	46.5	3.8	12.5	4.7	18.8	37.53
3.	RH 8812-OA × IOR-3	47	135	204	6.0	13.1	88.4	56.7	4.0	12.4	5.2	22.3	39.03
4.	RH 8812-OA × IOR-4	47	135	200	6.4	17.6	71.7	59.5	3.6	11.6	4.4	20.4	38.03
5.	RH 8812-OA × IOR-6	52	140	196	6.5	13.1	77.5	58.2	3.9	12.6	5.0	20.9	39.10
6.	RH 8812-OA × IOR-11	50	136	209	6.8	15.0	73.5	53.4	3.9	11.7	4.7	24.3	37.33
7.	RH 8812-OA × IOR-12	50	136	222	7.1	14.3	73.5	60.5	3.9	12.2	4.1	23.3	37.63
8.	RH 8812-OA × IOR-18	49	136	212	5.2	10.8	76.2	47.9	3.6	11.5	4.4	14.8	38.63
9.	RH 8812-OA × IOR-19	51	138	216	6.1	15.2	82.3	59.7	4.0	12.7	4.1	23.0	38.10
10.	RH 8812-OA × IOR-22	50	138	210	7.5	13.1	87.8	51.0	4.5	11.7	5.1	21.3	38.53
11.	RH 0749-OA × IOR-1	50	138	223	6.5	14.5	77.7	48.2	4.0	11.8	3.7	22.7	38.50
12.	RH 0749-OA × IOR-2	50	136	214	4.8	12.0	74.9	42.7	4.0	12.1	4.1	19.5	40.03
13.	RH 0749-OA × IOR-3	48	136	217	6.1	12.1	85.8	48.0	4.0	10.8	4.8	19.0	39.17
14.	RH 0749-OA × IOR-4	49	136	224	7.1	14.5	85.5	49.8	4.3	11.8	4.3	21.8	39.97
15.	RH 0749-OA × IOR-6	51	136	228	7.9	14.9	78.1	57.3	4.3	13.0	5.2	23.2	40.00
16.	RH 0749-OA × IOR-11	49	137	216	6.9	15.9	87.8	55.5	4.2	12.2	4.9	23.0	38.93
17.	RH 0749-OA × IOR-12	48	136	216	7.0	16.3	80.0	47.4	4.3	12.4	5.0	22.9	38.73
18.	RH 0749-OA × IOR-18	50	137	218	7.6	18.0	72.8	55.8	4.3	12.4	4.6	21.3	39.70
19.	RH 0749-OA × IOR-19	49	136	215	7.6	11.6	75.0	55.3	4.2	12.5	4.9	23.9	38.77
20.	RH 0749-OA × IOR-22	49	142	229	6.3	17.2	75.0	54.9	4.5	14.1	5.3	24.8	39.77
21.	RH 0630-OA × IOR-1	49	137	219	7.6	15.2	72.0	55.0	4.1	12.2	6.1	22.5	38.40
22.	RH 0630-OA × IOR-2	50	143	200	5.7	13.8	81.3	49.3	3.9	11.7	4.8	19.8	38.37
23.	RH 0630-OA × IOR-3	52	142	198	7.7	13.0	78.2	55.4	4.2	12.5	4.6	21.6	38.77
24.	RH 0630-OA × IOR-4	50	140	210	6.9	14.5	89.8	59.0	4.3	12.2	4.1	22.2	38.43
25.	RH 0630-OA × IOR-6	47	136	206	6.2	9.9	79.6	47.5	3.4	11.3	4.2	14.6	38.53
26.	RH 0630-OA × IOR-11	47	136	209	6.7	14.5	79.0	54.3	4.2	13.4	4.7	25.8	40.00
27.	RH 0630-OA × IOR-12	49	137	211	9.1	18.0	79.7	64.4	4.6	14.6	5.0	30.3	39.90
28.	RH 0630-OA × IOR-18	49	138	207	7.6	14.8	87.4	53.5	4.2	12.5	5.1	24.5	39.63
29.	RH 0630-OA × IOR-19	51	143	205	8.6	18.0	72.3	53.8	4.0	12.3	4.8	26.1	38.30
30.	RH 0630-OA × IOR-22	51	137	214	8.1	17.2	83.8	54.1	4.3	13.8	5.0	26.2	37.67
31.	RH 30-OA × IOR-1	50	138	202	7.7	19.4	91.6	62.2	4.1	14.4	4.8	31.2	39.70
32.	RH 30-OA × IOR-2	50	140	212	8.3	20.3	87.0	61.0	4.5	13.8	4.5	30.4	38.40
33.	RH 30-OA × IOR-3	47	138	195	6.2	17.7	74.1	52.9	3.9	12.0	4.3	24.9	38.63
34.	RH 30-OA × IOR-4	47	137	215	8.6	20.8	72.9	49.6	4.1	12.2	4.8	24.5	38.40
35.	RH 30-OA × IOR-6	47	138	204	7.8	20.7	86.6	51.7	4.2	12.5	4.7	25.5	38.37
36.	RH 30-OA × IOR-11	48	138	213	7.0	18.1	82.0	57.1	4.1	13.9	4.8	27.8	38.43
37.	RH 30-OA × IOR-12	51	143	214	7.6	19.7	83.9	61.6	4.0	11.9	4.3	28.4	39.20
38.	RH 30-OA × IOR-18	47	137	208	6.8	17.0	63.3	42.0	4.2	13.1	5.1	24.8	39.97
39.	RH 30-OA × IOR-19	47	135	205	5.9	18.4	73.7	49.9	4.1	13.3	4.7	28.3	38.20
40.	RH 30-OA × IOR-22	48	136	198	7.0	16.9	72.3	46.7	4.1	12.9	5.6	27.7	38.60
41.	RH 0555-OA × IOR-1	46	136	214	7.8	21.1	83.2	56.9	4.8	14.9	4.8	32.0	38.50
42.	RH 0555-OA × IOR-2	49	140	208	8.1	22.3	82.1	59.4	4.0	13.0	5.0	30.3	39.50
43.	RH 0555-OA × IOR-3	46	139	213	7.0	16.4	81.1	55.2	4.1	11.4	4.9	24.2	37.50
44.	RH 0555-OA × IOR-4	48	137	219	7.9	18.9	85.2	62.2	4.1	14.5	4.9	30.2	39.20
45.	RH 0555-OA × IOR-6	47	136	212	5.9	13.8	83.0	54.3	4.2	11.5	5.4	22.4	38.67
46.	RH 0555-OA × IOR-11	49	138	213	5.6	13.1	75.1	47.1	4.0	11.0	4.8	13.5	38.17
47.	RH 0555-OA × IOR-12	50	138	219	8.2	20.5	92.0	59.3	4.2	13.9	4.7	32.3	37.47
48.	RH 0555-OA × IOR-18	48	139	215	7.2	15.4	87.3	57.8	4.1	13.0	4.8	29.6	38.57
49.	RH 0555-OA × IOR-19	48	137	228	7.6	19.1	88.2	57.3	4.2	12.7	4.6	32.0	38.67
50.	RH 0555-OA × IOR-22	48	136	211	7.1	16.2	86.4	57.4	4.7	13.0	5.6	30.7	37.43

Table 5. Specific combining ability effects of crosses for different traits in Indian mustard

S. No	Crosses	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of primary branches/ plant	Number of secondary branches/ plant	Main shoot length	Number of siliqua on main shoot	Siliqua length	Number of seeds/ siliqua	1000-seed weight	Seed yield /plant	Oil content
1.	RH 8812-OA × IOR-1	-0.25	2.25**	-0.34	1.46**	0.91	1.50	-4.34	0.17	0.52	-0.23	-1.80	0.15
2.	RH 8812-OA × IOR-2	-2.79**	-2.95**	7.99	-0.60	-0.59	-3.66	-5.47*	-0.07	0.27	0.23	-1.64	-0.76**
3.	RH 8812-OA × IOR-3	-1.25*	-1.95**	0.55	-0.09	0.48	8.50	2.79	0.11	0.95	0.65*	3.24**	0.89*
4.	RH 8812-OA × IOR-4	-1.25*	-1.15	-11.03	-0.43	2.12*	-7.78	3.20	-0.31*	-0.50	0.03	-0.04	-0.30
5.	RH 8812-OA × IOR-6	3.28**	3.85**	-11.19	0.11	0.46	-1.82	4.20	0.09	0.79	0.30	2.96*	0.65*
6.	RH 8812-OA × IOR-11	0.81	-0.55	-0.34	0.69	1.50	-4.35	-0.38	0.01	-0.39	0.07	4.73**	-0.76**
7.	RH 8812-OA × IOR-12	-0.19	-1.49*	7.90	-0.18	-1.61	-6.68	1.55	-0.11	-0.38	-0.36	-0.83	-0.48
8.	RH 8812-OA × IOR-18	-0.19	-0.22	2.39	-1.14**	-2.61**	0.39	-3.74	-0.29	-0.61	-0.23	-4.89**	-0.19
9.	RH 8812-OA × IOR-19	1.35**	1.05	4.32	-0.56	0.55	5.61	4.24	0.10	0.41	-0.42*	-0.31	0.17
10.	RH 8812-OA × IOR-22	0.48	1.18	-0.25	0.75	-1.21	8.30	-2.05	0.29	-1.06*	-0.03	-1.43	0.61*
11.	RH 0749-OA × IOR-1	0.61	1.25	0.73	-0.87*	-1.43	-2.41	-3.70	-0.33*	-1.29*	-0.96**	-0.97	-0.84**
12.	RH 0749-OA × IOR-2	0.08	-2.29**	-4.05	-1.38**	-3.14**	-4.11	-6.49*	-0.16	-0.21	-0.42*	-2.15	0.62*
13.	RH 0749-OA × IOR-3	-0.72	-1.62*	3.50	-0.20	-0.96	5.26	-3.00	-0.12	-0.68	0.13	-1.27	-0.10
14.	RH 0749-OA × IOR-4	0.61	-0.49	2.15	0.02	-1.33	5.54	-3.61	0.15	-0.39	-0.11	0.04	0.51
15.	RH 0749-OA × IOR-6	1.48**	-0.49	11.21	1.33**	1.79*	-1.83	6.17*	0.25	1.12*	0.38	3.95**	0.42
16.	RH 0749-OA × IOR-11	0.01	0.45	-4.39	0.57	1.95*	9.31*	4.71	0.03	0.09	0.21	2.23	-0.29
17.	RH 0749-OA × IOR-12	-1.65**	-0.82	-8.14	-0.51	-0.05	-0.80	-8.58**	0.00	-0.26	0.42	-2.39*	-0.50
18.	RH 0749-OA × IOR-18	0.68	0.45	-2.65	0.97*	4.17**	-3.62	7.02**	0.13	0.19	-0.08	0.44	-0.25
19.	RH 0749-OA × IOR-19	-0.79	-1.29	-6.61	0.66	-3.45**	-2.29	2.78	0.01	0.12	0.40	-0.64	-0.29
20.	RH 0749-OA × IOR-22	-0.32	4.85**	8.26	-0.58	2.46**	-5.05	4.71	0.04	1.33**	0.05	0.74	0.72*
21.	RH 0630-OA × IOR-1	-0.59	-2.12**	8.86	-0.40	-0.93	-9.13*	-0.06	-0.12	-1.16*	1.25**	-2.38*	-0.39
22.	RH 0630-OA × IOR-2	0.21	3.01**	-5.81	-1.14**	-1.52	1.27	-2.97	-0.11	-0.95	0.14	-2.97*	-0.49
23.	RH 0630-OA × IOR-3	3.75**	2.68**	-3.14	0.71	-0.24	-3.35	1.29	0.16	0.67	-0.28	0.16	0.06
24.	RH 0630-OA × IOR-4	1.08*	2.15**	0.61	-0.85*	-1.55	8.76	2.47	0.25	-0.33	-0.45	-0.61	-0.47
25.	RH 0630-OA × IOR-6	-2.72**	-2.19**	0.68	-0.98*	-3.37**	-1.44	-6.86**	-0.63**	-0.94	-0.72**	-5.79**	-0.49
26.	RH 0630-OA × IOR-11	-2.19**	-2.25**	0.53	-0.29	0.34	-0.53	0.34	0.13	0.93	-0.14	3.91**	1.34**
27.	RH 0630-OA × IOR-12	-1.19*	-2.52**	-1.56	0.95*	1.46	-2.20	5.27*	0.38*	1.56**	0.30	3.85**	1.22**
28.	RH 0630-OA × IOR-18	-0.19	-0.92	-0.52	0.33	0.79	9.98*	1.65	0.14	0.00	0.20	2.45*	0.24
29.	RH 0630-OA × IOR-19	1.01*	4.01**	-4.92	1.13**	2.72**	-6.02	-1.93	-0.10	-0.45	0.10	0.37	-0.20
30.	RH 0630-OA × IOR-22	0.81	-1.85**	5.28	0.55	2.30*	2.67	0.78	-0.11	0.68	-0.40	1.00	-0.83**
31.	RH 30-OA × IOR-1	2.01**	0.41	-6.29	-0.16	-0.72	12.01*	8.33**	-0.12	0.65	0.08	2.37*	0.93**
32.	RH 30-OA × IOR-2	1.81**	0.88	7.38	1.66**	1.01	8.52	9.86**	0.47**	0.80	-0.11	3.57**	-0.45
33.	RH 30-OA × IOR-3	-0.65	-0.45	-5.06	-0.61	0.41	-5.88	-0.09	-0.09	-0.21	-0.44*	-0.53	-0.07
34.	RH 30-OA × IOR-4	-0.65	-0.32	6.47	0.95*	0.72	-6.61	-5.70*	0.00	-0.59	0.32	-2.36*	-0.49
35.	RH 30-OA × IOR-6	-1.45**	0.01	-0.02	0.71	3.39**	7.14	-1.47	0.21	-0.08	-0.22	1.17	-0.65*
36.	RH 30-OA × IOR-11	0.08	0.95	6.27	0.17	-0.01	4.05	4.28	-0.01	1.05*	0.05	1.92	-0.22
37.	RH 30-OA × IOR-12	2.08**	4.35**	2.63	-0.47	-0.90	3.61	3.66	-0.20	-1.50**	-0.30	-2.06	0.53
38.	RH 30-OA × IOR-18	-0.92	-1.05	0.89	-0.32	-1.01	-12.55**	-8.74**	0.12	0.21	0.26	-1.21	0.59*
39.	RH 30-OA × IOR-19	-1.72**	-2.79**	-3.40	-1.52**	-0.85	-3.10	-4.65	-0.01	0.25	0.08	-1.37	-0.29
40.	RH 30-OA × IOR-22	-0.59	-1.99**	-8.86	-0.43	-2.05*	-7.19	-5.49*	-0.36*	-0.58	0.28	-1.49	0.12
41.	RH 0555-OA × IOR-1	-1.79**	-1.79**	-2.96	-0.03	2.17*	-1.97	-0.24	0.40**	1.28*	-0.14	2.78*	0.15
42.	RH 0555-OA × IOR-2	0.68	1.35*	-5.51	1.46**	4.23**	-2.02	5.07	-0.13	0.10	0.16	3.19**	1.08**
43.	RH 0555-OA × IOR-3	-1.12*	1.35*	4.16	0.20	0.31	-4.53	-0.99	-0.07	-0.72	-0.06	-1.60	-0.78**
44.	RH 0555-OA × IOR-4	0.21	-0.19	1.80	0.31	0.05	0.09	3.63	-0.09	1.82**	0.21	2.97*	0.74*
45.	RH 0555-OA × IOR-6	-0.59	-1.19	-0.69	-1.16**	-2.28*	-2.06	-2.04	0.08	-0.89	0.25	-2.29*	0.08
46.	RH 0555-OA × IOR-11	1.28	1.41	-2.07	-1.14**	-3.79**	-8.48	-8.95**	-0.16	-1.68**	-0.18	-12.79**	-0.07
47.	RH 0555-OA × IOR-12	0.95	0.48	-0.82	0.22	1.10	6.08	-1.90	-0.08	0.58	-0.06	1.43	-0.78*
48.	RH 0555-OA × IOR-18	0.61	1.75**	-0.11	0.15	-1.34	5.81	3.81	-0.10	0.22	-0.15	3.20**	-0.39
49.	RH 0555-OA × IOR-19	0.15	-0.99	10.60	0.28	1.04	5.81	-0.44	0.01	-0.34	-0.15	1.95	0.60*
50.	RH 0555-OA × IOR-22	-0.39	-2.19**	-4.42	-0.29	-1.50	1.28	2.05	0.14	-0.37	0.12	1.17	-0.63*

* P ≤ 0.05, ** P ≤ 0.01

general combiner as it had good *gca* effects for almost all the characters. Similarly, among testers IOR-12 had the highest significant positive *gca* effects for seed yield and its attributing traits *viz*., branches per plant and number of siliqua on the main shoot. Others parents such as RH-30-OA, RH-0555-OA, IOR-12, IOR-19 and IOR-22 also possessed high *gca* for seed yield and yield contributing traits like early flowering, reduced plant height, number of primary and secondary branches per plant, long siliqua, long main shoot length, more number of seeds per siliqua, and more 1000-seed weight. These parents could be included in the breeding programme for the accumulation of favorable alleles in a single genetic background.

The mean performance and *sca* effects of hybrids for yield and its component traits are given in **Table 4 and Table 5,** respectively. Among the crosses evaluated the maximum mean seed yield per plant was obtained in the cross RH 0555-OA x IOR-12. The crosses RH 0630-OA × IOR-12 and RH 30-OA × IOR-1 also had recorded high single plant yield along with more number of branches, more number of siliqua and high 1000-seed weight, which are considered as desirable crosses based on mean performance.

The *sca* effect along with mean performance is a crucial criterion for the selection of hybrids. The specific combining ability is the departure from the performance predicted based on general combining ability (Allard, 1960). When the *sca* effects are observed, the cross RH 0630-OA × IOR-12 had expressed the highly significant and positive *sca* effects for seed yield per plant, the number of seeds per sillqua, siliqua length, siliqua on the main shoot, primary branches per plant and oil content. This cross also exhibited a negative and significant *sca* effect for flowering and maturity. Also, the cross RH 8812-OA × IOR-3 had exhibited positive and significant *sca* effects for the 1000-seed weight and seed yield per plant. For the characters such as primary branches per plant and secondary branches per plant, hybrids RH 0749-OA × IOR-6, RH 0749-OA × IOR-22 and RH 0749-OA × IOR-18 exhibited positive and significant sca effects. While cross, RH 0630-OA × IOR-11 had exhibited positive and significant *sca* effects for the oil content. However, none of the crosses revealed significant desirable sca effects for plant height. Dholu *et al*. (2014), Tomar *et al*. (2015), Meena *et al*. (2015) and Dahiya *et al*. (2018) reported similar results on combining ability in Indian mustard with a different set of material. These crosses could be utilized for heterosis and pedigree breeding to obtain better recombinants for desirable traits in later generations.

REFERENCES

Allard, R. W. 1960. Principles of Plant Breeding. *John Wiley and Sons Inc.,* New York.

Dahiya, N., Bhajan, R. and Pant, U. 2018. Heterosis and combining ability for different traits in local germplasm and varietal crosses in *Brassica juncea* (L). *Int. J. Cemi. Stud*., **6**: 1884-1887.

Dholu, V. K., Sasidharan, N., Suthar, K., Bhusan, B. and Patel, J. N. 2014. Heterosis and combining ability analysis in Indian mustard [*Brassica juncea* (L.) Czern. & Coss.]. *Int. J. Agric. Sci*., **10**: 102-107.

Ghosh, S. K., Gulati, S. C. and Raman, R. 2002. Combining ability and heterosis for seed yield and its components in Indian mustard [*Brassica juncea* (L.) Czern. & Coss.]. *Indian J. Genet*., **62**: 29-33.

Gnanasekaran, M. and Thiyagu, K. 2021. Gene action, combining ability and standard heterosis for seed cotton yield and fibre quality components in upland cotton. *Electron. J. Plant Breed.,* **12**: 325-334. [Cross Ref]

Gupta, P., Chaudhary, H. B. and Lal, S. K. 2011. Heterosis and combining ability analysis for yield and its components in Indian mustard [*Brassica juncea* (L.) Czern & Coss.]. *Front. Agric. China*., **4**: 299-307. [Cross Ref]

Kempthorne, O. 1957. An introduction to genetic statistics. John Wiley and Sons, Inc.; New York.

Meena, H. S., Kumar, A., Ram, B., Singh, V. V., Meena, P. D., Singh, B. K. and Singh, D. 2015. Combining ability and heterosis for seed yield and its components in Indian mustard (*Brassica juncea* L.). *J. Agric. Sci. Technol*., **17**: 1861-1871.

Patel, P. B., Patel, P. J., Patel, J. R. and Patel, P. C. 2021. Elucidation of genetic variability and inter-relationship studies for seed yield and quality traits in Indian mustard [*Brassica juncea* (L.) Czern and Coss]. *Electron. J. Plant Breed.,* **12**: 589-596. [Cross Ref]

Singh, P. K. and Choudhary, R. D. 1977. Biometrical methods. In: Quantitative Genetic Analysis, Kalyani Publishers, New Delhi, pp. 178-185.

Tomar, A., Singh, M. and Singh, S. K. 2015. Genetic analysis of yield and its components based on heterotic response and combining ability parameters in Indian mustard [*Brassica juncea* (L.) Czern & Coss.]. *Progress. Agric*., **15**: 85-91.