International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2024; 8(5): 201-204
www.biochemjournal.com
Received: 02-02-2024
Accepted: 10-03-2024

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Combining ability analysis for seed yield and its attributes in Indian mustard [*Brassica juncea* (L.) Czern and Coss]

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DOI: https://doi.org/10.33545/26174693.2024.v8.i5c.1069

Abstract
The experimental material comprised of fifty six genotypes consisting of six cytoplasmic male sterile lines (GM 1 Ogura, GM 2 Ogura, GM 2 Oxyrrhina, GM 1 Siffolia, GM 2 Siffolia and GM 1 Mori) and seven fertile lines (GM 3, SKM 149, SKM 303, Mori 'R' 1-18, RSK 88, RSK 95 and RSK 96) crossed in line × tester mating design. The resultant forty two hybrids along with their thirteen parents and standard check (NRCHB 506) were evaluated in randomized block design at Castor-Mustard Research Station, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar (Gujarat) during *rabi* 2020-2021.
The analysis of variance for parents, hybrids and parents *vs.* hybrids revealed that mean sum of squares of parents were highly significant for majority of the traits except siliqua length. Whereas, hybrids differed highly significant for all the characters.
The ratio of σ2gca/ σ2sca was found less than unity for the traits *viz*., days to maturity, total number of branch per plant, total number of siliqua per plant, siliqua length, number of seeds per siliqua, seed yield per plant, 1000 seed weight and oil content which suggested the greater role of non-additive gene action for the inheritance for these traits.
Among the parents, female GM 1 Mori was good general combiner for seed yield per plant, total number of siliqua per plant and 1000 seed weight and GM 1 Ogura was good general combiner for seed yield, total number of branch per plant and total number of siliqua per plant. Whereas, male parent RSK 88 was good general combiner for seed yield per plant, total number of branch per plant, total number of siliqua per plant, siliqua length, number of seeds per siliqua, 1000 seed weight and oil content.
Best three hybrids which possessed significant positive SCA effects for seed yield per plant over standard check NRCHB 506 (12.20 g) were GM 1 Ogura × RSK 88 (21.41 g), GM 2 Oxyrrhina × SKM 303 (20.37 g) and GM 1 Siffolia × RSK 88 (19.95 g).

Keywords: Line x Tester, Combining ability, gene action, Indian mustard

Introduction

Indian mustard belongs to family Brassicaceae and genus Brassica, popularly known as rai or *raya*. Indian mustard or brown mustard [*Brassica juncea* (L.) Czern &Coss] is a natural amphidiploid (2n = 36) of *Brassica rapa* (2n = 20) and Brassica nigra (2n = 16). Mustard is largely self-pollinated but certain amount (<18.7%) of cross pollination may take place. Indian mustard is mainly used for extraction of oil. Seed of Indian mustard contain 38 to 40 percent oil and is mainly utilized for human consumption throughout Northern India for cooking as well as frying purpose. Besides, its oil also serves as an important raw material for industrial products like soap, paints, lubricants etc. Its oil cake is rich in protein but due to its high glucosinolate content it is not suitable for animal feed. Combining ability analysis is one of the powerful tools to test the value of parental lines to produce superior hybrids and valuable recombinants (Singh *et al*., 2013) [10]. Further, for developing better genotypes through hybridization, the choice of suitable parents is of great concern. The concept of combining ability was developed by Sprague and Tatum (1942) [11]. According to them, general combining ability (GCA) measures the average performance of a line in cross combinations while specific combining ability (SCA) measures the deviation of certain expected combinations on the basis of average performance of the lines involved.

The combining ability analyses also provide information about the nature and magnitude of gene action involved in the expression of various quantitative characters. Keeping all this in view, the present investigation on combining ability analysis for seed yield and its attributes in Indian mustard [*Brassica juncea* (L.) Czern & Coss] was undertaken with the objective to estimate the general and specific combining ability effects and variances.

Materials and Methods

The experimental material consisting of 6 cytoplasmic male sterile lines, *viz*., GM 1 Ogura, GM 2 Ogura, GM 2 Oxyrrhina, GM 1 Siffolia, GM 2 Siffolia and GM 1 Mori were crossed with 7 diverse restorers *viz*., GM 3, SKM 149, SKM 303, Mori 'R'1-18, RSK 88, RSK 95 and RSK 96 in a line x tester mating design during *rabi* 2019 to obtain 42 hybrids. Resulting hybrid combinations were tested in the *rabi* 2020 along with 13 parents (6 A lines and 7 R lines) and 1 check in RBD design with three replication at Castor-Mustard Research Station, S. D. Agricultural University, Sardarkrushinagar. Sardarkrushinagar which is situated at semi-arid region of North Gujarat. Geographically, it is situated at 24°.31' N latitude and 72°.32' E longitude with an altitude of 154.52 meters above the mean sea level. The soil of the experimental field was sandy loam with pH 7.5. Each treatment was planted in one row, of 3 m length and 45 cm apart, plant to plant distance was maintained 15 cm by thinning. The recommended agronomical practices and plant protection measures were adopted as per requirement. The observations were recorded on five randomly selected plants from each replication for all the traits *viz*., plant height (cm), total number of branches per plant, total number of siliquae per plant, length of siliqua (cm), number of seeds per siliqua, seed yield per plant (g), 1000 seed weight (g) and oil content (%) except days to flowering and days to maturity which were recorded on plot basis. Final mean data pertaining to various characters were analyzed as per the procedure of RBD. The combining ability analysis was performed for a Line x Tester mating design as per the method suggested by Kempthorne (1957) [3]. The oil content of each samples were estimated in percentage by using Nuclear Magnetic Resonance (NMR) Technique (Tiwari *et al*. 1974) [14].

Results and Discussion

The analysis of variance for combining ability revealed that the mean sum of square for all the characters except plant height, and silique length (Table 1). This indicated significant contribution of females towards general combining ability variance component for these traits. The variance due to males (tester) was significant for all characters under study. The line x tester interaction was significant for all the characters except days to flowering and plant height. This indicates significant contribution of hybrids for specific combining ability variance component. The variance component due to females was higher than that of males for days to flowering, days to maturity, total number of branches per plant and 1000 seed weight. The ratio of σ2 gca/σ2 sca below than unity for all characters except days to flowering and plant height which suggested greater role of non-additive gene action in the inheritance of these traits. The presence of predominantly large amount of non-additive gene action it must be required to maintain heterozygosity in the population. These results are in accordance with the findings of Meena *et al*. (2017) [6], Rashmi *et al*. (2018) [1] and Thanmichon *et al*. (2018) [12]. Whereas, the ratio of σ2 gca/σ2 sca found more than unity for days to flowering and plant height which suggested greater role of additive gene action in the inheritance of these traits. The above results are in agreement with the results of Kumar *et al*. (2017) [4], Dahiya *et al*. (2018) [1] and Shrimali *et al*. (2018) [9].

Table 1: Analysis of variance (Mean sum of square) for combining ability and estimates of components of variance for ten …characters in Indian mustard

Source of variation	d.f	Days to flowering	Days to maturity	Plant height	Total number of branch per plant	Total number of siliqua per plant	Siliqua length	Number of seed per siliqua	Seed yield per plant	1000 seed weight	Oil content
Replications	2	0.92	0.20	174.35	0.49	487.01	0.03	0.03	1.01	0.003	0.31
Crosses	34	8.98*	10.68**	122.55*	52.93**	3960.99**	0.09**	2.06**	56.89**	2.65**	8.88**
Females	4	47.10**	39.46**	153.78	123.66**	5752.04**	0.02	1.33**	57.04**	5.71**	5.31**
Males	6	6.60**	8.28**	242.70**	81.19**	6607.95**	0.12**	1.68**	69.02**	1.84**	9.15**
Females × males	24	3.22	6.48**	87.30	34.08**	3000.73**	0.09**	2.27**	53.83**	2.34**	9.41**
Error	68	1.92	2.68	72.89	4.15	192.24	0.03	0.22	1.02	0.005	0.36
σ^2Females		2.09**	1.57**	3.17	4.27*	131.01	-0.004	-0.04	0.15	0.16	-0.20
σ^2Males		0.23	0.12	10.36*	3.14	240.48	0.002	-0.04	1.01	-0.03	-0.02
σ^2_{gca}		1.31**	0.97	6.16	3.80*	176.63*	-0.0013	-0.04	0.51	0.08	-0.12
σ^2_{sca}		0.43	1.27**	4.80	9.98**	936.16**	0.02**	0.69**	17.60**	0.78**	3.18**
$\sigma^2_{gca}/\sigma^2_{sca}$		3.05	0.76	1.28	0.38	0.19	-0.06	-0.06	0.03	0.10	-0.04

*, ** Significant at 5 percent and 1 percent levels of significance, respectively

General combining ability

The perusal of data (Table 2) revealed that none of the parents was identified good general combiner for all the characters under study. Among the parents, GM 1 Ogura was good general combiner for days to flowering, days to maturity, total number of branche per plant, total number of silique per plant and seed yield per plant; RSK 88 was good general combiner for total number of branches per plant, silique length, number of seeds per siliqua, seed yield per plant, 1000 seed weight and oil content. Present results are in concurrence with those of Meena *et al*. (2015) [5].

Table 2: Estimation of general combining ability (GCA) effects of parents for various characters in Indian mustard

	Parents	Days to flowering	Days to maturity	Plant height	Total number of branch per plant	Total number of siliqua per plant	Siliqua length	Number of seed per siliqua	Seed yield per plant	1000 seed weight	Oil content
Lines	GM 1 Ogura	-2.66**	-2.25**	0.46	2.45**	19.64**	0.03	0.12	0.67**	-0.12**	-0.19
	GM 1 Siffolia	0.87**	0.13	-3.30	0.09	-6.58*	-0.04	0.27**	0.48*	0.30**	0.04
	GM 2 Siffolia	0.82**	0.04	-2.07	-0.92*	-13.21**	0.00	0.03	0.38	0.48**	-0.54**
	GM 2 Oxyrrhina	0.39	1.42**	1.50	1.96**	-15.60**	-0.01	-0.02	-2.87**	-0.85**	-0.13
	GM 1 Mori	0.58	0.66	3.41	-3.58**	15.76**	0.01	-0.40**	1.34**	0.19**	0.82
	S.Em. +	0.3027	0.3573	1.8631	0.4445	3.0256	0.0366	0.1012	0.2201	0.0150	0.1304
Testers	GM 3	1.03**	0.08	5.95**	0.59	17.50**	0.10*	0.23	2.66**	0.11**	-0.12
	SKM 149	0.30	-0.06	-2.05	-2.94**	-37.71**	-0.03	-0.25*	-3.45**	-0.07**	-0.82**
	SKM 303	-0.37	-1.32**	-6.11**	0.28	-3.46	-0.05	-0.10	0.39	0.05**	-0.71**
	Mori 'R' 1-18	-1.10**	1.01*	0.62	-0.94	9.89**	-0.10*	-0.45*	-1.18**	-0.16**	1.31**
	RSK 88	0.23	-0.39	-0.38	3.74**	23.65**	0.15**	0.58**	1.13**	0.38**	0.74**
	RSK 95	0.16	0.61	3.95	1.67**	4.99	0.01	-0.06	1.91**	0.35**	-0.45**
	RSK 96	-0.24	0.08	-1.98	-2.40**	-14.86**	-0.07	0.07	-1.46**	-0.65**	0.05
	S.Em. +	0.3581	0.4227	2.2044	0.5260	3.5800	0.0433	0.1198	0.2604	0.0178	0.1542

*, ** Significant at 5 percent and 1 percent levels of significance, respectively

Specific combining ability

Best three hybrids which possessed significant positive sca effects for seed yield per plant, total number of branch per plant, total number of siliqua per plant, number of seed per siliqua and 1000 seed weight were GM 2 Oxyrrhina × SKM 303 (9.85), GM 1 Ogura × RSK 88 (6.61) and GM 1 Siffolia × RSK 88 (5.34). For total number of branch per plant, GM 1 Ogura × RSK 88 (60.34%) hybrid showed positive and significant standard heterosis whereas hybrid GM 2 Oxyrrhina × SKM 303 (13.23%) exhibited positive and significant standard heterosis for siliqua length while hybrid GM 1 Ogura × RSK 88 (11.44%) exhibited positive and significant standard heterosis for total number of siliqua per plant. which had good genetic architecture on the basis of sca effects and had contribution of Poor × Average, Good × Good and Good × Average combiners. The similar results were also reported by Patel *et al*. (2013) [7], Meena *et al*. (2015) [5] and Gideon *et al*. (2015) [2]. Based on above result it can be concluded that line GM 1 Mori was good general combiner for seed yield per plant (1.34), total number of siliqua per plant (15.76) and 1000 seed weight (0.19) and GM 1 Ogura was good general combiner for seed yield (0.67), total number of branch per plant (2.45) and total number of siliqua per plant (19.64). Whereas, male parent RSK 88 was good general combiner for seed yield per plant (1.13), total number of branch per plant (3.74) and total number of siliqua per plant (23.65), siliqua length (0.15), number of seeds per siliqua (0.58), 1000 seed weight (0.38) and oil content (0.74). It suggested that these parents might be presumed to be relatively greater number of favorable alleles for developing superior hybrids or varieties of Indian mustard. Based on high SCA effect, hybrids GM 1 Ogura × RSK 88, GM 2 Oxyrrhina × SKM 303, GM 1 Siffolia × RSK 88, GM 1 Mori × RSK 95 and GM 2 Siffolia × GM 3 were identified as best specific cross combination for seed yield per plant. These hybrids need to be tested in multiplication trials for stability analysis.

Table 3: The estimates of specific combining ability (SCA) effects for various characters in Indian mustard

Sr. No.	Crosses	Days to flowering	Days to maturity	Plant height	Total number of branch per plant	Total number of siliqua per plant	Siliqua length	Number of seed per siliqua	Seed yield per plant	1000 seed weight	Oil content
1	GM 1 Ogura × GM 3	0.59	1.11	5.48	1.33	-12.98	-0.07	0.07	-2.76**	-0.71**	0.79*
2	GM 1 Ogura × SKM 149	-0.01	-0.09	6.14	-4.67**	33.37**	-0.21*	0.15	-0.15	-0.69**	1.16**
3	GM 1 Ogura × SKM 303	0.66	0.85	-8.46	-2.89*	4.72	-0.09	-0.80**	-4.30**	-0.58**	-2.40**
4	GM 1 Ogura × Mori 'R' 1-18	-0.61	-1.82	-3.19	0.87	-10.36	0.06	0.21	4.37**	0.93**	-1.00**
5	GM 1 Ogura × RSK 88	-1.28	-1.42	-1.86	2.59*	-10.79	0.15	0.19	6.61**	1.01**	0.89*
6	GM 1 Ogura × RSK 95	1.46	1.58	6.48	0.65	-5.60	0.09	-0.04	-1.43*	0.21**	-0.25
7	GM 1 Ogura × RSK 96	-0.81	-0.22	-4.59	2.12	1.65	0.09	0.23	-2.34**	-0.16**	0.82*
8	GM 1 Siffolia × GM 3	-0.27	-1.27	1.24	1.30	3.05	0.14	0.58*	-1.49*	-0.10*	1.42**
9	GM 1 Siffolia × SKM 149	-0.87	1.20	-0.76	-1.10	-9.67	0.03	0.46	2.17**	0.46**	1.06**
10	GM 1 Siffolia × SKM 303	-0.20	0.13	-1.03	-1.53	9.14	-0.18	-0.35	-3.46**	-0.13**	1.07**
11	GM 1 Siffolia × Mori 'R' 1-18	-0.47	0.13	2.90	0.70	21.73**	-0.04	0.33	0.55	-0.03	-1.26**
12	GM 1 Siffolia × RSK 88	1.53	1.53	-3.10	4.48**	7.90	0.18	0.30	5.34**	0.51**	-1.41**
13	GM 1 Siffolia × RSK 95	0.60	-0.13	0.57	-1.45	-33.71**	-0.14	-1.13**	-1.62**	-1.11**	-1.65**
14	GM 1 Siffolia × RSK 96	-0.33	-1.60	0.17	-2.38*	1.54	0.00	-0.19	-1.50*	0.42**	0.76*
15	GM 2 Siffolia × GM 3	0.78	-0.84	-8.33	-0.43	6.08	-0.00	-0.18	3.13**	0.52**	-1.80**
16	GM 2 Siffolia × SKM 149	1.85*	-2.37*	-1.33	2.84*	-47.57**	0.12	-0.23	-4.02**	0.49**	-1.06**
17	GM 2 Siffolia × SKM 303	-0.82	0.90	-1.27	2.08	-58.89**	-0.09	0.22	3.71**	0.41**	-0.89*
18	GM 2 Siffolia × Mori 'R' 1-18	0.58	0.90	4.33	0.77	26.83**	-0.01	0.90**	-1.74**	0.21**	3.40**
19	GM 2 Siffolia × RSK 88	-0.75	-2.04*	7.00	-0.58	-0.73	-0.02	0.21	-4.00**	-0.68**	2.10**
20	GM 2 Siffolia × RSK 95	-1.35	0.63	-5.33	-3.64**	19.39*	-0.02	-1.09**	-1.20*	-0.31**	0.92**
21	GM 2 Siffolia × RSK 96	-0.29	2.83**	4.93	-1.04	54.91**	0.03	0.18	4.14**	-0.65**	-2.67**
22	GM 2 Oxyrrhina × GM 3	-1.79*	1.78	6.76	-0.57	17.74*	-0.19	-1.39**	-0.45	-0.38**	1.66**

23	GM 2 Oxyrrhina × SKM 149	-1.06	0.91	-4.24	3.10**	6.95	-0.06	-0.71**	0.68	-0.98**	-2.45**
24	GM 2 Oxyrrhina × SKM 303	0.28	-1.15	2.50	5.00**	47.63**	0.46**	1.01**	9.85**	2.11**	1.04**
25	GM 2 Oxyrrhina × Mori 'R' 1-18	0.34	-0.15	-0.24	-0.24	-30.05**	0.07	0.42	-3.07**	-0.94**	-0.96**
26	GM 2 Oxyrrhina × RSK 88	1.01	0.25	-4.57	-2.05	17.52*	-0.07	0.46	-6.40**	-0.44**	-0.63
27	GM 2 Oxyrrhina × RSK 95	-0.26	-0.75	-4.24	-3.93**	14.98	-0.23*	0.90**	0.61	0.50**	-0.37
28	GM 2 Oxyrrhina × RSK 96	1.48	-0.89	4.03	-1.31	-74.77**	0.01	-0.70*	-1.22*	0.13**	1.72**
29	GM 1 Mori × GM 3	0.69	-0.79	-5.14	-1.63	-13.89	0.12	0.92**	1.57**	0.67**	-2.06**
30	GM 1 Mori × SKM 149	0.09	0.34	0.19	-0.16	16.92*	0.11	0.34	1.33*	0.71**	1.30**
31	GM 1 Mori × SKM 303	0.09	-0.72	8.26	-2.66*	-2.60	-0.10	-0.08	-5.80**	-1.80**	1.19**
32	GM 1 Mori × Mori 'R' 1-18	0.15	0.94	-3.81	-2.10	-8.14	-0.09	-1.86**	-0.11	-0.17**	-0.18
33	GM 1 Mori × RSK 88	-0.51	1.68	2.52	-4.44**	-13.90	-0.23*	-1.16**	-1.55**	-0.40**	-0.96**
34	GM 1 Mori × RSK 95	-0.45	-1.32	2.52	8.36**	4.95	0.31**	1.35**	3.64**	0.72**	1.35**
35	GM 1 Mori × RSK 96	-0.05	-0.12	-4.54	2.62*	16.67*	-0.11	0.48	0.93	0.27**	-0.63
	S.Em. +	0.8008	0.9452	4.9292	1.1761	8.0051	0.0969	0.2678	0.5823	0.0398	0.3449
	Range	-1.79 to 1.85	-2.37 to 2.83	-8.46 to 8.26	-4.67 to 8.36	-74.77 to 54.91	-0.23 to 0.46	-1.86 to 1.35	-6.40 to 9.85	-1.80 to 2.11	-2.67 to 3.40
	+ve significant	1	1	0	7	10	2	8	11	17	17
	-ve significant	1	2	0	6	5	3	6	17	17	13

*, ** Significant at 5 percent and 1 percent levels of significance, respectively

Conclusion

None of the parents was identified good general combiner for all the characters under study. Among the parents, line GM 1 Ogura was good general combiner for seed yield per plant, total number of branch per plant and total number of siliqua per plant and another line GM 1 Mori was good general combiner for total number of siliqua per plant, seed yield per plant and 1000 seed weight and oil content. Whereas, tester RSK 88 was good general combiner for seed yield per plant, total number of branch per plant and total number of siliqua per plant, siliqua length, number of seeds per siliqua, 1000 seed weight and oil content. Best three hybrids which possessed significant positive SCA effects for seed yield per plant over standard check NRCHB 506 (12.20 g) were GM 1 Ogura × RSK 88 (21.41 g), GM 2 Oxyrrhina × SKM 303 (20.37 g) and GM 1 Siffolia × RSK 88 (19.95 g).

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